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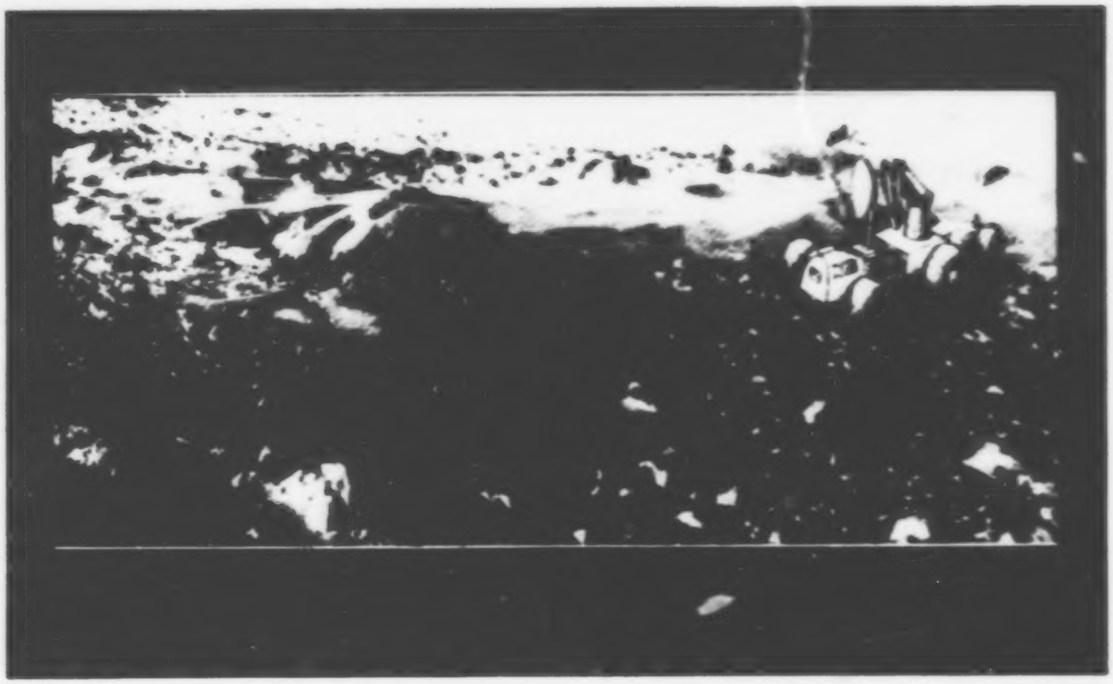
WORKSHOP ON
MARS SAMPLE RETURN SCIENCE



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WORKSHOP ON
MARS SAMPLE RETURN SCIENCE

Edited by

Michael J. Drake, Ronald Greeley, Gordon A. McKay, Douglas P. Blanchard, Michael H. Carr,
James Gooding, Christopher P. McKay, Paul D. Spudis, and Steven W. Squyres

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Introduction

The Mars Sample Return Science Workshop was held at the Lunar and Planetary Institute in Houston, Texas, from November 16–18, 1987. It was attended by approximately 125 individuals from 10 nations. The workshop was conceived by the Lunar and Planetary Sample Team (LAPST). LAPST is an advisory committee to NASA with responsibility for allocation of lunar samples and cosmic dust to qualified investigators, and for the promotion of sample-related science. The workshop was sponsored by the Lunar and Planetary Institute with additional support from the Planetary Geosciences section of the Solar System Exploration Division and the Exobiology section of the Life Sciences Division of NASA. Eighty-six abstracts were submitted, from which 21 posters were presented and 46 presentations were given orally. This report was prepared by members of the Scientific Organizing Committee. The somewhat uneven lengths of different sections represent the idiosyncracies of the subsection authors, rather than an assessment of the relative importance of different Mars subdisciplines.

Program

Monday Morning, November 16th

* - Speaker for Contributed Talks

Introduction **M. J. Drake**

SESSION 1 - OVERVIEW AND PRECURSOR MISSIONS
Chairman: M. J. Drake

Keynote Speakers:

Mars Observer Database
M. Carr

Soviet Mission Database
G. Burba

Overview of Mars: Viking Results
M. Carr

Overview of Mars: SNC Meteorite Results
H. Wänke

Posters

Monday Afternoon, November 16th

SESSION 2 - MARTIAN MAGMATIC HISTORY
Chairman: G. McKay

Keynote Speakers:

Accretion and Primary Differentiation of Mars
M. J. Drake

Chronology and Geochemistry: Speculations on the Igneous History of Mars
J. H. Jones

Petrologic Constraints on the Pressure, Temperature, Time and Composition of the Martian Interior: Samples and Experiments
J. R. Holloway

Posters

Contributed Talks:

R. L. Korotev* L. A. Haskin
Some Lessons from Apollo for a Sampling Strategy on Mars for Understanding the Origin of the Ancient Igneous Crust and the Composition of the Martian Mantle

J. W. Delano*
Glass: A Source of Data Leading to Constraints on the Volcanic, Impact, and Atmospheric Histories of Mars

A. H. Treiman*
Crystal Fractionation in the SNC Meteorites: Implications for Sample Selection

R. Greeley*
Mars Volcanism: What, When, and Where?

Discussion

SESSION 3 - QUARANTINE ISSUES

Contributed Papers:

H. J. Melosh*
Earth Rocks on Mars: Must Planetary Quarantine Be Rethought?

J. Rummel (Invited Talk and Discussion Leader)
Quarantine: Implications for and from Science Requirements

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Poster Presentation:

J. E. Davidson W. F. Mitchell
Lunar Placement of Mars Quarantine Facility

Tuesday Morning, November 17th

SESSION 4 - SURFACE MODIFYING PROCESSES
Chairman: R. Greeley

Keynote Speakers:

The Role of Impact Cratering for Mars Return
P. H. Schultz

Mars Sampling Strategy and Aeolian Processes
R. Greeley

Fluvial Processes on Mars: Erosion and Sedimentation
S. W. Squyres

Posters

Contributed Talks:

B. K. Lucchitta*
Valles Marineris, Mars: An Optimum Science-Sample Site

A. Woronow*
Processing and Redistribution of Surface and Subsurface Samples by Impact Cratering

Poster Presentations:

J. C. Aubele L. S. Crumple
Constraints on Mars Sampling Based on Models of Basaltic Flow Flow Surfaces and Interiors

A. Basu
Trenching and Coring a Martian Sand Body in Search of Sedimentologic Evidence of Sand Transport and Deposition

G. Flynn D. McKay
Meteorites on Mars

J. R. Zimbelman
Present Imaging Limitations to Providing a Geological Assessment of Potential Sample Return Sites on Mars

Discussion

Tuesday Afternoon, November 17th

SESSION 5 - CLIMATE, ATMOSPHERE, AND VOLATILE INVENTORY
Chairman: S. W. Squyres

Keynote Speaker:

Martian Weathering Products as Tracers of Climate Change and Atmosphere/Hydrosphere Evolution on Mars
J. L. Gooding

Contributed Talks:

R. Prinn B. Fegley*
Chemical Interactions Between the Present-day Martian Atmosphere and Surface Minerals: Implications for Sample Return

R. G. Burns*
Sampling the Oxidative Weathering Products and the Potentially Acidic Permafrost on Mars

H. E. Newsom*
Samples from Martian Craters: Origin of the Martian Soil by Hydrothermal Alteration of Impact Melt Deposits and Atmospheric Interactions with Ejecta During Crater Formation

I. P. Wright M. M. Grady* C. T. Pillinger
Stable Isotopic Studies of N,C,N,O and S

Discussion

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Keynote Speaker:

Climate, Atmosphere, and Volatile Inventory Evolution: Polar Processes, Climate Records, Volatile Physical Inventories
J. B. Pollack

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P. A. J. Englert*
Cosmogenic Nuclides in the Martian Surface: Constraints for Sample Recovery and Transport

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Deciphering Martian Climatic History Using Returned Samples

T. D. Swindle*
Noble Gases as Tracers of the Origin and Evolution of the Martian Atmosphere and the Degassing History of the Planet

D. Bogard*
How Well Do We Know the Martian Abundances of Highly Volatile Elements?

Discussion

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A Reason for Sampling Martian Ice

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Computer Modeling of the Mineralogy of the Martian Surface, as Modified by Aqueous Alteration

A. P. Zent
The Record of Martian Climatic History in Cores and Its Preservation

Wednesday Afternoon, November 18th

SESSION 7 - SAMPLING SITES AND STRATEGIES

Chairman: M. H. Carr

Keynote Speaker:

Search for Mars Lander/Rover/Sample-Return Sites - A Status Review
H. Masursky

Contributed Talks:

G. Neukum*
Absolute Ages from Crater Statistics: Using Radiometric Ages of Martian Samples for Determining the Martian Cratering

E. A. King*
Hellas Basin Ejecta: A Prime Stratigraphic Marker and Sampling Target

D. H. Scott*
Mars Sample Return: Recommended Sites

Discussion

Posters

Keynote Speaker:

Sampling Strategies on Mars: Remote and Not-So-Remote Observations from a Surface Rover
R. B. Singer

Contributed Talks:

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How Successful Were the Lunar Sampling Tools?: Implications for Sampling Mars

B. C. Clark*
Martian Regolith Geochemistry and Sampling Techniques

L. O. Yin* J. I. Trombka
In-situ XRF and Gamma Ray Spectrometer for Mars Sample Return Mission

T. E. Economou* A. L. Turkevich
Insitu Chemical Analyses of Extraterrestrial Bodies

Discussion

Poster Presentations:

N. G. Barlow
The Ridged Plains as a Possible Landing Site for the Mars Sample Return Mission

R. Grard
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Mars Rover Sample Return: An Exobiology Science Scenario

D. H. Scott K. Tanaka
Martian Sample Sites: Examples Based on a Global Geologic Perspective

T. W. Thompson L. Roth
Earth-Based Radar Contribution to Mars Sample Return

Wednesday Morning, November 18th

SESSION 6 - LIFE SCIENCES
Chairman: C. P. McKay

Keynote Speaker:

Continuing the Biological Exploration of Mars
H. P. Klein

Invited Talks:

A. Banin
The Soil of Mars

D. J. Des Marais
Search for Martian Fossil Communities: Sediment Sites and Sample Handling

E. I. Friedmann
Trace Fossils of Microbial Colonization on Mars: Criteria for Search and for Sample Return

G. V. Levin
The Life on Mars Dilemma and the Sample Return Mission

Discussion

Contributed Talks:

J. Oro[*]
Martian Oxidation Processes and Selection of Ancient Sedimentary Samples for Bio-Organic Analysis

C. W. Gehrke[*] R. W. Zumwalt C. Ponnamperuma
The Search for and Identification of Amino Acids, Nucleobases and Nucleosides in Samples Returned from Mars

D. A. Cadenhead[*]
Surface Compositional and Structural Aspects of Martian Samples

Poster Presentations:

Mancinelli R. L. Schwartz D. E.
Exobiology and the Search for Biological Signatures on Mars

SUMMARY OF TECHNICAL SESSIONS

WORKSHOP PRODUCT

The intent of the workshop was not to discuss what we already know about Mars from Viking and, perhaps, SNC meteorites: rather it was to discuss what could be learned from returned samples. Orbital and network science were deliberately excluded as beyond the scope of the workshop and are deserving of a workshop in their own right. The following issues were explicitly addressed:

- science questions for all disciplines interested in sample return
- natures of samples
- masses of samples
- surface locations of samples
- sample collection procedures
- curation of samples on Mars and at Earth

These questions were addressed to various degrees of success in the workshop, the tendency of scientists wanting to discuss science sometimes overwhelming the practical goals of the workshop. The summaries that follow are explicitly designed to respond to these questions. One specific point needs emphasis: Sample masses specified are generally *minimum* masses needed by an individual investigator and do not take into account the desirability of multiple analyses by different investigators.

OVERVIEW AND PRECURSOR MISSIONS

Four invited talks were given. The talks were designed to review existing knowledge rather than to discuss science to be performed on returned samples. Consequently, only a brief listing of speakers and subjects is given, together with an authoritative reference to which the reader is referred.

Our probable knowledge base after the Mars Observer Mission was reviewed by M. Carr of the U.S. Geological Survey, Menlo Park. Carr's presentation left most of the audience largely in the dark because of an area-wide power failure caused by a vicious storm that hit 10 minutes after the session started. The reader is referred to "THE MARS OBSERVER MISSION—International Astronautical Federation IAF 86-318," published by Pergamon Press, for a detailed discussion of the Mars Observer Mission.

Soviet mission plans were outlined by G. Burba of the Vernadsky Institute of Geochemistry, Moscow. Plans include an approved mission to the moons of Mars (PHOBOS) and the reader is directed to the document "PHOBOS—Exploration of Phobos, Mars, Sun, and Interplanetary Space," published by the Academy of Sciences of the USSR Space Research Institute, 1987. The PHOBOS mission has a substantial set of instruments directed specifically to Mars studies. Further missions in the planning stage but not yet approved include one or more rover missions, sometimes referred to as MARS 94, to develop rover technology and explore the surface of Mars. These activities are to culminate in an automated Sample Return Mission, tentatively scheduled for 1996 or 1998, to land on the surface and return samples to Earth for study in terrestrial laboratories.

Our knowledge base of Mars from spacecraft missions, especially Viking, was reviewed by Carr. An excellent review of our current understanding of Mars may be found in Carr (1981, *The Surface of Mars*, Yale Univ. Press, New Haven, CT). This presentation emphasized the enormous leaps in our comprehension of the geologic and climate history of Mars, but clearly indicated the quantum jump in knowledge that would result from a Mars Rover Sample Return Mission.

Finally, H. Wänke of the Max-Planck-Institut für Chemie, Mainz, reviewed the evidence connecting the SNC meteorites to Mars, and our consequent knowledge of Mars if these rare meteorites are indeed from that planet. An excellent source to review our current knowledge is *Geochimica et Cosmochimica Acta*, v. 50, pp. 875–1091. If these meteorites are indeed serendipitous samples of Mars, they tell us something (although not everything) about the igneous history of Mars, but are less suited or unsuited to addressing scientific questions related to surface modifying processes; climate, atmosphere, and volatile inventory history; sample geophysics; and exobiology.

PRIMARY DIFFERENTIATION AND MAGMATIC HISTORY

Major Science Questions

This session focused on what could be learned about the history of martian large-scale differentiation, magmatism, and magmatic processes from the study of returned samples. The session included invited talks by M. Drake, J. Jones (who graciously filled in for D. DePaolo on short notice), and J. Holloway, and contributed talks by R. Korotev and L. Haskin, J. Delano, A. Treiman, and R. Greeley. The speakers pointed out many important science questions that may be addressed through study of igneous materials. These include:

1. *Martian origin of SNC meteorites.* Drake pointed out that much has been learned about the shergottite parent body through studies of SNC meteorites. However, this information cannot be applied to Mars with any degree of certainty until a martian origin for SNCs has been unambiguously demonstrated. Thus, a key measurement to be made on any sample returned from Mars is its oxygen isotopic composition. Measurements on several samples with enough variability in oxygen isotopic ratios to define a slope one-half mass fractionation line will suffice to bind the SNC meteorites to Mars or to demonstrate that they cannot be samples of that planet.

2. *Martian accretion and core formation.* Drake suggested that these issues can be addressed through analysis of incompatible siderophile, chalcophile, and lithophile elements in martian basaltic rocks. Plots of siderophile or chalcophile vs. refractory lithophile incompatible elements may be used to establish abundances of siderophile and chalcophile elements in the martian mantle. These abundances may, in turn, be used to calculate the nature of the core-forming process and whether accretion was homogeneous or heterogeneous, using metal/silicate partition coefficients. Mars may then be compared with the Earth and Moon. A question raised during discussion of this issue involved the degree to which weathering will compromise the value of samples for addressing this question. The answer depends on the minerals and elements involved. Some minerals are much more susceptible to weathering than others. For some elements, useful data have been obtained from terrestrial rocks that are very old, or that have been under water. For other elements, the slightest degree of weathering or alteration of host phases will be detrimental.

3. *The chronology of formation and evolution of the martian atmosphere.* This topic can be studied through analysis of atmosphere samples combined with studies of primordial volatiles contained in martian volcanic rocks and glasses, and trapped ancient atmospheric gases that may possibly be contained in impact glasses. Noble gas daughter products of parents such as ^{129}I and ^{40}K are particularly useful. Several points were raised during discussion. Concern was expressed regarding the effect of recycling on gas isotopic ratios, to which Drake replied that there will no doubt be debates over the interpretation of data, but that we at least need samples in order to obtain any data at all. Another participant noted that a grab sample of atmosphere is likely to be deficient in water, and that to obtain better information regarding the water inventory, samples of polar ice or permafrost should also be returned.

4. *Chronology and processes of mantle differentiation and crust formation.* Jones suggested that Mars probably has both a light rare earth element (LREE)-enriched crust and a LREE-depleted mantle. To constrain the differentiation processes by which these reservoirs arose, samples should contain both young, fresh basalts (presumably derived from the mantle) and samples of crust. The crustal sample might be something as simple as an aliquot of windblown dust. Alternatively, depending on the mechanism of dust formation, a sample of real crustal rock may be required. Rocks should be large enough that mineral separates can be made for internal isochrons, implying that these samples should be several grams each. The basalt samples should be as fresh as possible and come from a terrain of known crater density, so that the isotopic age can be used to calibrate the crater density age (see below). Recent impact craters may aid sampling, but it is unclear whether samples from rampart craters should be considered because it has been suggested that such samples may be hydrothermally altered. A variety of rocks of very different ages would also be useful in reconstructing the geologic evolution of the planet. Key issues raised during the discussion of this topic included the wisdom of going after samples that are likely to be much like SNC meteorites vs. collecting a broader suite of materials from more complex sites, and the mode of formation of the martian dust and whether it is likely to be representative of average martian crustal rocks in the sense that terrestrial loess is representative of the average continental crust.

5. *Calibration of cratering ages.* Several speakers mentioned this issue, and it was the topic of considerable discussion. This calibration can be done through radiometric dating of basalts from geologic units with good crater density statistics, thereby allowing assignment of absolute ages to geologic units based on crater densities observed from orbit. This would permit an accurate reconstruction of the distribution of martian volcanic activity through geologic time, thereby providing major constraints on the thermal evolution of Mars. Intercalated sediment samples collected for other reasons (see subsequent sections) could also be dated absolutely.

6. *Mantle mineralogy and composition.* This topic was addressed by Holloway. Experimental and theoretical petrologic analysis of martian igneous rocks can provide estimates of pressure and temperature distributions in mantle source regions. These estimates, in turn, can be combined with the distribution of volcanic activity through time to provide important constraints on the thermal history of Mars. The quality of the information depends on the sample type, decreasing from xenoliths of mantle material to primary magma compositions to suites of fractionated magmas. Newly developed high-pressure apparatus allows phase equilibria studies at pressures equivalent to the martian core, thereby providing the exciting opportunity of experimental characterization of an entire major planet. Experiments on synthetic analogues whose compositions are constrained by geophysical

properties are already providing useful information about likely P-T conditions and phase assemblages in the martian mantle. These experiments suggest that the depth at which the density of a melt exceeds that of coexisting minerals may be relatively shallow on Mars, thereby precluding eruption of magmas from considerable depth. This conclusion remains tentative, however, until the effects of volatiles on melt density have been experimentally investigated. During the discussion period, it was noted that the current experiments do not consider sulfur, and that S-bearing experiments are needed to better constrain the mantle phase relationships and magma densities. It was also noted that it is essential that unaltered rocks be available in order to determine primary magma compositions and hence unravel mantle P-T relationships. Moreover, it was pointed out that SNC meteorites are highly fractionated, and fairly far removed from primary magma compositions, so that a lot of petrologic and geochemical "unwinding" is required to obtain mantle P-T and phase information from these samples if they are proven to be from Mars. More primitive basalts would make this job much easier.

Other Contributions

Korotev and Haskin presented a paper discussing lessons from the Apollo program that they believe should be applied to the sampling strategy for a Mars mission. Based on their experiences in trying to interpret Apollo data, they believe that in order to study the igneous differentiation of Mars, it would be much better to have many 0.5–5 g samples than a few larger samples. They also believe that core samples will not generally be more useful than "grab" samples for igneous studies. It is important to have samples that are typical of the terrain they are intended to represent rather than potentially ambiguous samples from regions that are the interface between two or more types of terrain. During the discussion of this paper, the opinion was expressed that it is only sensible to collect cores if the scale of the phenomenon to be sampled by coring is known in advance, so that the length of the required core is known. In reply to this opinion, it was noted that cores may have some utility in providing unweathered samples or samples of uniform shape that can be more easily handled by automated mechanisms. It was also noted that cores may be essential for disciplines other than igneous petrology. One participant urged caution in directly applying the lessons of Apollo to Mars because the processes that produce the rocks and soil are very different on those two planetary bodies.

Delano presented a paper outlining information that might be obtained from the analysis of any glasses that might be returned from Mars. Information from volcanic glasses might include the chronology of volcanic events, the redox state of the martian mantle, primary magma compositions, and trapped primordial gas. Information from impact glasses might include the impact flux through time, the chemical diversity of the martian crust, the composition of aliquots of martian atmosphere trapped at different times, and the times of major volcanic injections of gas into the atmosphere. During the discussion, a question was raised concerning the loss of volatiles through glass by diffusion and hence how well ancient trapped gas is represented by the gas still retained in the glass. It was noted that the degree of gas loss will depend on the element and its diffusion coefficient, but that diffusion coefficients can be measured, so this problem is tractable. Another question concerned the likelihood of collecting glass and the ability to identify glass deposits through remote sensing. Delano did not advocate searching explicitly for glass, but rather being careful to identify any glass that may happen to be collected and returned. A participant noted that optical remote-sensing techniques can unambiguously identify glass, so searching for glass deposits may not be so farfetched.

Treiman presented a paper discussing the shortcomings of SNC meteorites as representative martian samples. He noted that these meteorites are poor geochemical samples of their parent planet because all but one are crystal cumulates and therefore do not represent magma compositions. Instead, we must play geochemical games to try to deduce magma compositions from these cumulate samples. Because they must have cooled slowly enough to permit crystal accumulation, it is likely that the SNC meteorites formed near the bottoms of rather thick lava flows. To maximize the chances of collecting samples more representative of magmas, it would be best to collect samples from thin flows. Discussion included one comment expressing doubt that we really know unambiguously that most shergottites are cumulates. The opinion was expressed that we should not base sampling strategy on a preconceived notion of what sort of sample we want to collect, but rather should focus on basic characterization of whatever we find.

Greeley presented a paper describing the various styles of martian volcanism and their distributions in space and time. Volcanism spans the entire visible history of Mars. Early eruptions were predominantly flood lavas. Plains-forming volcanic materials constitute about 45% of the surface of Mars. The earliest "central" volcanos are the highland patera located near Hellas. Potential sample sites of high priority include (1) young basalt plains south of Tharsis, (2) the old central volcano Tyrrhena Patera, and (3) possible "ignimbrite" flows in Memnonia. Discussion included a comment concerning the high scientific value of terrestrial deep-sea basalts for sampling magmatic volatiles because they retain their full complement of volatiles due to the high pressure under which they crystallize, and speculations that similar samples might be present in the northern volcanic plains. In response to questions from the audience, Greeley speculated that the flood basalt eruptions might provide the best samples of primary magma that has undergone a minimum of interaction with crustal rocks, while a series of deposits in the equatorial region that have been called ignimbrites might provide samples of siliceous volcanic rocks. Another participant noted that the youngest volcanic deposits in Valles Marineris might be silicic tuffs, but the opinion was expressed that it would be a big mistake to go after those samples because they might end up being very difficult to interpret, whereas the interpretation of samples from a lava flow is likely to be much less ambiguous.

After the formal presentations, there was a general discussion session. One issue concerned information about Mars that the SNC meteorites fail to provide (even assuming they are from Mars), and that might otherwise be provided by fresh basalts collected on Mars during a sample return mission. This information includes calibration for dating of volcanic units by the crater counting technique, ground truth for orbital remote sensing, and composition of primitive magmas (SNCs are not very primitive, having rather low Mg/[Fe + Mg] ratios). Another issue involved techniques for selecting optimum samples with a rover, including remote sensing and *in situ* analysis. The question of developing new terrestrial laboratory instrumentation in preparation for a return of martian samples and the impact of such new instrumentation on Mars sampling requirements was also raised. It was noted that for some sample types, collection of a representative sample presented a more fundamental limitation on minimum sample size than our ability to analyze small quantities of material, but for other sample types or scientific problems, improvement in analytical sensitivity would result in a corresponding reduction in required sample mass.

Nature and Masses of Samples Required

Sample requirements to address the above science questions range from very general to highly specific. Virtually any samples with enough oxygen to permit precise measurement of isotopic abundances will be adequate to test the connection of SNCs with Mars. Most investigations require fresh, unweathered basaltic rocks of sufficient mass to provide a representative sample and to permit analysis for a complete suite of elements by a variety of techniques. The specific mass required for a representative sample depends on grain-size, but is on the order of a few grams for fine- to medium-grained basalts. For homogeneous volcanic glasses, a few tenths of a gram provides adequate mass for virtually complete analysis. Maximum scientific return would be provided by a variety of basalts of different ages and tectonic settings. Large samples are not needed for any of the proposed investigations. Many 1–10 g samples from a variety of basalt units would be vastly preferable to a small number of kilogram-sized samples.

Some investigations require specific types of samples. Experimental determination of the mineralogy, temperature, and depth of basalt source regions requires accurate knowledge of the bulk composition of primary magmas. Rocks representing such magmas might be identified *in situ* on the basis of high Mg/Fe ratio and absence of cumulus crystals, if the rover has sufficient analytical capability. Enough material is required to provide a representative sample, as discussed above.

In addition to samples of fresh basalt, study of crust/mantle differentiation requires samples of the ancient crust. Terrestrial loess provides an excellent average for the Earth's crust, and martian windblown dust might also provide such an average. However, the origin of the martian dust is controversial, and it might not be an appropriate sample for this investigation. Hence, unaltered samples of ancient highlands rocks are also desirable.

Calibration of cratering ages requires fresh, readily-dated basalts from units that have been dated with adequate precision by the crater-counting technique. For optimum calibration, it would be desirable to have several basalts with cratering ages ranging from 2 to 4 b.y.

Several science questions can be well addressed through study of volcanic or impact glasses. Soil samples are one likely source of such glasses. However, preservation of glass for a significant fraction of martian geologic history was considered problematical, and the primary advocate of glass investigations recommended that the objective of collecting glass should not seriously influence sampling strategy. On the other hand, glass can be readily identified by spectral techniques, so that large deposits of pyroclastic glass might be identified from orbit, and a capable rover might be able to search a local site for samples of glass.

Most speakers specifically mentioned sample freshness as a highly desirable characteristic. Many investigations require that the samples be unweathered, so that their original mineralogies and chemical compositions are preserved. This requirement is crucial for some studies, such as analysis of primordial or impact-implanted gases in basaltic rocks or glasses. It is less crucial for other studies, such as Sm-Nd isotopic studies, or U-Pb isotopic investigation of resistate minerals such as zircons, because of the relative immobility of the elements or resistance to weathering of the minerals involved. However, with few exceptions, the proposed studies are likely to yield less equivocal results on fresh, unweathered samples.

Curation

Curation was not specifically addressed during this session, primarily because most of the above studies require no special curation techniques beyond those developed for the Apollo lunar samples. Contamination control, meticulous sample splitting and processing, and careful documentation are much more important for these investigations than any special handling procedures, such as preservation of low temperatures, etc.

Major Issues Regarding Sampling Strategy

Several important sampling strategy issues arose during the Magmatic History session, some of which were sufficiently general that they continually resurfaced throughout the rest of the workshop. A fundamental issue is the degree of sample diversity and geologic complexity desired of the landing site. One extreme point of view is that the mission should go to a very simple site on a terrain where a small number of sample types can be found, but where those samples can be related unambiguously to a geological unit observed from orbit. Furthermore, the geological unit should be a typical representative of a widely occurring type of terrain of obvious planetary significance. The other extreme point of view is that the mission should go to a complex site, where a wide variety of sample types can be collected, and hope that detailed sample studies combined with *in situ* analyses performed during rover traverses and orbital geochemical analyses will enable these samples to be placed in geologic context.

Proponents of the "simple site" viewpoint argued that soil samples collected at lunar landing sites near the mare-highland boundaries were complex mixtures of mare and highlands components, were thus extremely difficult to interpret, and hence failed to yield unambiguous information regarding representative compositions for each lithologic unit. In addition, simple site advocates argued that in order to calibrate the meteorite flux for dating geologic units by crater counting, it will be necessary to obtain readily-dated samples that can be unambiguously related to basaltic units with sufficient crater density to provide precise crater counting ages. Thus, a relatively simple site is required. Finally, it was noted that even very simple lunar sites provided a variety of basalt types with a wealth of information regarding mantle source region isotopic characteristics and evolution.

Proponents of the "complex site" viewpoint argued that lunar analogies should be applied with caution, since processes are very different on the two planets. For example, the lack of impact mixing on Mars makes it less likely that simple sites will provide the variety of samples that they did on the Moon. Moreover, complex site advocates argued that a single type of sample such as basalt, which might be the only sample returned from a very simple site, might be very interesting for igneous petrologists, but might be of much less interest to other disciplines. Thus, in order to provide "something for everyone," a complex site with a variegated sample set is desirable. Although many participants expressed strong opinions on this important issue, no consensus was reached.

Another recurring issue that arose during this session involved the desirability of having sufficient analytical capability on the rover to provide basic sample characterization and classification. Such characterization would have many benefits, including allowing *in situ* identification of samples that address specific science issues, helping eliminate duplicate samples of the same rock type, ensuring diversity of the sample suite, permitting identification of fresh unweathered material, etc.

A third recurring issue involved whether core samples are necessary for the proposed investigations. It was generally agreed that for most igneous petrologic studies, cores offer no advantage over other sample types. One participant pointed out that the length of a core must be commensurate with the scale of the phenomenon to be sampled, and there is no a priori way to determine the scales of martian phenomena to be sampled by coring. Another participant pointed out that, because of the complexity of lunar impact processes, the stratigraphic information contained in lunar cores was much less than hoped before the missions. Another participant noted that even without stratigraphic information, cores might be desirable because they could provide fresh samples from the interior of weathered outcrops, and would provide samples of known geometry that might facilitate packaging. The general consensus was that cores are not needed for addressing most igneous petrology problems, but they may be essential for other disciplines.

Another major issue arising during this session involves the need for collecting additional young basalts in view of the fact that we have eight igneous samples of possible martian origin in the SNC meteorites. Some participants felt that the possible martian origin of SNCs relegated collection of young basalts to lower priority than samples that address questions which cannot be answered by SNCs, such as the nature of the ancient crust, evolution of volatile inventories, etc. Petrologists responded with several arguments supporting collection of basalts. According to these participants: (1) it is not certain that SNCs are from Mars, thus it would be foolhardy to count on them as the only source of information about the martian mantle, and consequently, not try to return young basalts; (2) because their provenance is not known, SNCs cannot help with calibration of cratering ages or provide ground truth for orbital remote sensing; (3) because they are evolved rather than primary magmas, SNCs do not provide important information about mantle mineralogy or P-T conditions, and thus about martian thermal history; and (4) because their isotopic systems have been disturbed by shock, information provided by SNC melts about key isotopic ratios in mantle reservoirs is ambiguous, leaving major uncertainties about the evolution of the mantle with time. It is worth noting that we would not be able to conclude that lunar meteorites are indeed from the Moon if we had not already analyzed samples known to be from the Moon as a result of the Apollo and Luna missions.

EXOGENIC SURFACE MODIFYING PROCESSES

The surface of Mars reflects a wide variety of processes, including those originating internally, such as volcanism and tectonism, and those originating externally. External, or exogenic, processes include impact cratering, landslides, and surface modification by wind and water. Although these processes complicate sampling strategies because they redistribute materials and potentially destroy the geological context, exogenic processes can also provide samples of diverse compositions and ages by eroding materials from large areas and concentrating the materials in sites of deposition.

Impact cratering is a ubiquitous planetary process. On Mars, craters range in size from a few kilometers in diameter to the ~2000-km Hellas basin. As discussed by P. Schultz, there are several sampling strategies related to impact cratering. Samples of ancient basin massifs on Mars may be analogous to those obtained at the Apollo 15 site on the Moon and could provide petrologic information on the ancient martian crust. In addition, samples of impact-generated breccias associated with basins may contain a record of early martian volatiles.

Samples of ejecta from small (≤ a few kilometers) craters could be advantageous from several perspectives. Much of Mars is mantled with windblown and fluvial deposits that vary in thickness from centimeters to many meters. Fresh impact craters could penetrate these deposits and excavate bedrock samples. Moreover, ejecta deposits reflect the stratigraphy of multilayered "targets," with the deepest layers generally being redeposited on or near the crater rim. Thus, progressive sampling from the outer ejecta to the rim of a crater may effectively sample the vertical stratigraphy of the target area. However, Schultz cautions that the presence of an atmosphere on Mars may result in ejecta mixing and destruction of the systematic pattern typically seen around impact craters on the Moon.

In the absence of samples from all major regions and rock units, impact crater "counts" provide the only means to obtain dates of planetary surfaces. However, reliable dates are possible only when the cratering flux for a given planet has been established. On the Moon, a calibration was established by obtaining ages for samples known to be derived from specific cratered surfaces. As pointed out by G. Neukum, such a strategy should have a high priority on Mars. As a minimum, samples and dates should be obtained for both the oldest features, such as impact basins, and the youngest features, such as late-stage lava flows, for which impact crater statistics can be obtained.

As discussed by R. Greeley, aeolian or wind-related activity constitutes the dominant modifying process on Mars today and is likely to have occurred throughout the history of Mars. Aeolian processes involve the erosion, transportation, and deposition of material by the wind and have the potential for separating some particles by size, density, and composition, homogenizing other materials via dust storms, and altering the surface composition of rocks by the formation of desert varnish coatings. Deposits of windblown material can vary in thickness from a few microns to tens of meters.

Scanning electron microscopy of dune sands could provide clues to the history of their formation and transportation. Samples from north polar dune deposits could address the question of whether windblown materials consist of holocrystalline grains or are aggregates of finer material, and could resolve the question of the sediment source for the north polar dunes. Young deposits in the Memnonia region have been proposed as volcanic, aeolian, or polar in origin. Samples could resolve the question of their origin, the results of which have implications for many aspects of the evolution of Mars.

Aeolian processes have several implications for general sampling strategies. First, dark areas may be good sites for obtaining bedrock surfaces, as they are presumed to be wind-swept. However, observations of high-resolution Viking Orbiter images show that some dark areas consist of sand dunes. Thus, the precise nature of aeolian processes as related to low-albedo regions must be well known. Moreover, it is likely that aeolian deposits are common on most surfaces and must be anticipated in selection of potential landing sites. Wind can also lead to desert pavement and varnished surfaces, which would compromise the interpretation of remote-sensing measurements.

Fluvial (running water) processes were discussed by S. Squyres. Networks of small valleys occur in the ancient cratered highlands and are considered to result from the flow of liquid water under warmer climatic conditions early in the history of Mars. Many of these valleys emptied into impact basins or other local topographic lows and possibly led to the formation of temporary lakes or playas. Deposits of water-lain sediments in these areas could be high-priority sample sites to assess the early volatile history of Mars. Moreover, they could be candidate sites to meet exobiology sample objectives.

Many outflow channels exceed 1000 km in length, cross terrains of varied origins and ages, and cut downward to depths of several kilometers. Deposits of material eroded from the channels could provide samples with a great diversity of ages and compositions, although the geological context of such samples would probably be indecipherable. Outflow channel erosion also exposes thick stratigraphic sections through the martian crust along the channel walls.

The canyonlands of the Valles Marineris also provide a cross-section of the martian crust several kilometers deep and may display a geologic history for the planet similar to the Grand Canyon on Earth. As described by B. Lucchitta, ancient crust is probably represented at the bottom of the canyon, with progressively younger rocks toward the top of the sequence. In addition, deposits of several ages occur within the canyon. Intermediate age rocks may be of volcanic origins. Although a highly mobile roving vehicle might be able to negotiate the steep and hazardous terrain that would be involved in sampling the entire canyonland sequence, Lucchitta proposed that landslides derived from the canyon walls could provide a ready access to a wide suite of samples. Depending upon the selection of a landing site within the canyonlands, samples of diverse materials and ages could be collected within a 10–50 km radius. Such samples, however, would do little to provide calibrations for crater-counts.

Summarizing, the modification of the martian surface by various exogenic processes must be taken into account in the selection of potential sampling sites on Mars. Depending upon the primary scientific objectives for the sample(s) to be collected, such processes may help or hinder meeting these objectives.

MARTIAN CLIMATE, ATMOSPHERE, AND VOLATILE INVENTORY

This session focused on the sampling requirements for questions concerning the history of the martian climate and volatile endowment. The summary here is drawn from invited reviews by J. Gooding and J. Pollack, and contributed talks by B. Fegley, R. Burns, H. Newsom, M. Grady, R. Kuzmin, P. Englert, D. Paige, T. Swindle, and D. Bogard.

Mars, like the Earth, has an atmosphere, a complex climate, and a history of surface processes largely controlled by volatiles. This Earth-like nature is one of the characteristics of Mars that makes it most intriguing for exploration. Moreover, there is clear evidence in the martian geologic record that the planet has undergone substantial climatic change, both long-term and short-term.

Evidence indicates that Mars was once a warmer and wetter place than it is now. The primary geologic evidence for this statement is provided by the valley systems in Mars' ancient terrain. The discharges implied by the valley morphology and dimensions are modest. Streams of such sizes would be expected to become quickly choked with ice under the present climatic conditions. That early Mars was warmer, wetter, and hence more Earth-like than it is now is also consistent with detailed modeling of the evolution of the martian atmosphere. How warm and how wet Mars really was is not known, however. It is also unclear when the transition to the present colder, drier climate occurred, although it seems to have taken place fairly soon after formation of the planet.

Evolution and periodic variation of the martian climate has continued up to the present. The strongest evidence for this statement is provided by the thin, regular layers present in the martian polar regions. These layers are apparently composed of intermixed dust and H_2O ice. The layering is believed to result from a complex modulation of deposition and erosion in the polar regions by periodic climatic changes. The changes seem to be driven by periodic variations in Mars' orbital elements resulting from complex gravitational interactions with the sun and Jupiter. The details of the relationship between orbital element variations and climate change are not understood, however.

The total volatile inventory of Mars is also poorly known. Important possible reservoirs for H_2O include the atmosphere, the polar deposits, ground ice (especially at high latitudes), adsorbed water on regolith grains, water of hydration in minerals, and perhaps even subsurface liquid water or brines. CO_2 reservoirs include the atmosphere, seasonal frost caps, regolith adsorption, and perhaps carbonates. Both the distribution and quantities of these volatiles are poorly understood, and only limited improvement in understanding of some crucial issues is to be expected from the Mars Observer mission. A fuller understanding of the martian volatile inventory, such as would result from a sample return mission, is important for several reasons. First, we must know the total volatile inventory of each of the terrestrial planets if we are to understand the way in which the planets received their volatiles originally (and hence, for example, how the Earth's atmosphere and oceans formed). Second, we can use the extent and timing of volatile outgassing that has taken place on Mars to infer the nature of the outgassing process and how it is related to the observed record of volcanic activity and climate change. Finally, the availability of H_2O on Mars will be a crucial issue for future human exploration of the planet.

A record of Mars' climatic history and clues to its volatile inventory are preserved on the planet's surface. In fact, because Mars has been less geologically active than the Earth, we have access there to a much more complete record of early climate than we do for the climate of the early Earth. Reading this record should be a major goal of a Mars Rover Sample Return Mission. In order to do so, there are five principal sampling objectives: ground ice, polar deposits, carbonates, atmosphere, and soil.

Ground Ice

Ground ice is likely to be the largest single reservoir of near-surface water on Mars. Estimates of the total water outgassed on Mars vary widely, but unless the correct value is considerably less than those most commonly proposed (of the order of 100 m if the water were uniformly spread over the surface of the planet), no other sink for martian water appears to have the capacity necessary. Because of the likely volumetric importance of the ground ice reservoir, we must understand it thoroughly in order to understand the overall martian volatile inventory.

It is possible to calculate the zones within the martian regolith in which ground ice should be thermodynamically stable under the present climate. Such calculations suggest that ice should be stable at modest depths from the poles down to a latitude of 30°–40° in each hemisphere. The top of the zone of stability reaches the surface very near the poles (where the perennial H_2O ice is present at the surface), and becomes gradually deeper with decreasing latitude. The calculations suggest that ice may be stable at depths less than 1 m at latitudes higher than 40°–50° in each hemisphere. Calculations of subsurface ice migration indicate that an initially ice-rich equatorial region can become desiccated in a time much less than the age of the planet.

Geomorphic evidence appears to confirm this general picture of ground ice distribution. Characteristic landforms apparently produced by viscous relaxation of topography are found in some areas of the planet. The most plausible explanation of the relaxation appears to be deformation of ice-rich ground caused by gradual creep of interstitial ice. The distribution of these landforms implies that ice is common at latitudes poleward of ±30°, but much less so at lower latitudes. Details of the morphology of the creep features suggest that ice may extend from near the surface to depths of ~2 km in high-latitude heavily cratered terrain; this depth is consistent with the expected depth of comminution by the impact process. Investigation of the depth to which impacts must penetrate to produce fluidized ejecta deposits is also consistent with the general picture of H_2O close to the surface at high latitudes, but much deeper near the equator. The H_2O concentrations required to form these landforms are unknown.

Several specific sampling goals for ground ice can be stated. These include determining (1) the areal distribution and minimum depth to which ground ice extends as a function of latitude and geologic material; (2) the concentration of ground ice present in a variety of different geologic materials; (3) the manner in which ground ice is physically present (in pores, in fractures, etc.); and (4) the history of ground ice at certain key locations. Goals (1), (2), and (3) involve direct *in situ* measurements. Aspects of the history of ground ice at a given location can be inferred directly from the D/H ratio and the oxygen isotopic composition of the ice. Changes in the local concentration of water can also be inferred from abundances of certain cosmogenic nuclides in the upper regions of the soil. (The amount of H present in the soil strongly influences the energy spectrum of subsurface neutrons. If water is present, the products of neutron capture reactions will be relatively more abundant. The half lives of these products vary, so that their relative abundances and vertical profiles can yield information about changes of water distribution with time.)

Acquisition of ground ice samples will probably involve coring. In order to learn something about the areal distribution of ice, as well as to maximize the probability of obtaining an ice-rich core at some location, it will be desirable to estimate the depth to ground ice and its concentration before coring. A neutron/gamma-ray spectrometer onboard the rover may be useful for this purpose. The cores should be as deep as feasible, to maximize both the chances of finding ice and the knowledge gained about the vertical distribution of ice. If high latitudes (at least 45°–50°) can be reached, a coring depth of 1–2 m may be sufficient. Samples in more than one geologic unit are desirable. In order to minimize the amount of sample to be returned, the cores should be subsampled. A capability to do a cursory inspection of a core that allows intelligent subsample selection is therefore desirable. Individual subsamples should be at least several cm^3 in volume to allow characterization of the soil/ice texture. This volume should also be adequate for isotopic studies. If prevention of thawing or sublimation of the ice during the return to Earth is deemed to be important, thermal isolation of subsamples will be necessary.

Polar Deposits

The layered deposits at the martian poles form sequences several kilometers thick. Individual layers visible in Viking images are a few tens of meters thick, and are laterally continuous over large distances. It is likely that finer layering is present at a scale smaller than the best image resolution. Material is apparently deposited each winter, as dust placed in the atmosphere by dust storms is transported to the polar regions and deposited along with the seasonal CO_2 frost cap. When the CO_2 evaporates with the onset of summer, the dust is left behind, mixed with H_2O ice that resides at the poles year round. The layering seems to result somehow from the periodic variations in Mars' obliquity and orbital eccentricity, plus precession of the equinoxes. All of these effects cause periodic variations in annual mean insolation at a given latitude on the planet. The variations have characteristic periods of $\sim 10^5$ to 10^6 yr. Insolation variations can have at least two effects. One is to vary the amount of H_2O ice present at the poles and available for formation of the deposits. The other is to vary global atmospheric pressure, as changes in regolith temperature can substantially affect the amount of atmospheric CO_2 stored by regolith adsorption. Periodic changes in atmospheric pressure of up to an order of magnitude may be possible, driving the dust-carrying capacity of the atmosphere, and hence the polar deposition rate.

One important characteristic of the cyclic climate variations recorded in the polar layered deposits is that they may be closely analogous to terrestrial ice ages. Changes in the Earth's orbital elements are often cited as a driving mechanism for terrestrial climate cycles, but the problem is complicated severely by such factors as the small amplitude of the variations and energy buffering and transport by the oceans. Mars is a simpler system, having no oceans but displaying orbital variations of large amplitude (e.g., up to 20° in obliquity). If samples from the polar layered deposits could be obtained, a record of these climate cycles might be read. Another exciting possibility is that such samples could preserve a record of martian climate over much shorter time scales as well. It appears that material is deposited at the poles annually, so it may be possible to identify individual annual layers in returned samples. It is known that martian climate shows significant year-to-year variability, for instance in the occurrence and intensity of global dust storms. A core from the layered deposits could preserve a detailed record of thousands of years of martian climate.

As with ground ice cores, it may be possible to make important inferences about polar deposition and erosion processes from isotopic studies. An especially interesting possibility for the poles is the analysis of dust for short-lived cosmogenic nuclides like ^{10}Be and ^{26}Al produced by primary cosmic-ray interactions. Because these isotopes decay with half lives comparable to deposition timescales over scales of a few meters, their vertical profiles in cores will be a strong function of erosion or deposition rate.

The primary sampling goal for the polar layered deposits is to obtain a representative record from locations throughout at least one full deposition cycle. Although individual layers are tens of meters thick, it will not be necessary to drill continuous cores of such great length. The layers have been deeply eroded. It should be possible to sample at any depth in a given layer by moving the rover no more than a few hundred meters. Individual core lengths of 1–2 m should be quite sufficient. As for ground ice cores, polar cores should be subsampled rather than returned in bulk. The important parameter to maximize for a polar core subsample of a given mass or volume is the length of the record preserved. Therefore long, thin, vertical subsamples are strongly preferred over other geometries. At least one continuous subsample ~1 m long taken at the top of a layer is desirable to provide a continuous record of the most recent deposition and the vertical concentration profile of cosmogenic nuclides. Thermal isolation of the samples during the return to Earth will be crucial to preserve ice distribution and layering. Shielding from the space radiation environment (or at least careful monitoring of radiation) will also be important to understand and minimize modification of the concentrations of some cosmogenic nuclides.

Carbonates

To date, carbonate deposits have not been detected on Mars. However, there is good reason to believe that they are present. Two independent lines of evidence suggest that a substantial amount of CO_2 was outgassed early in Mars' history. First, the apparent evidence for a formerly warmer climate seems to require a significant greenhouse effect on Mars early in its history. A more dense CO_2 atmosphere is a reasonable means of producing such a greenhouse. Second, if something on the order of 100 m of water was outgassed on Mars, and if the H_2O/CO_2 ratio in Mars is similar to the Earth, CO_2 outgassing sufficient to produce an atmosphere with a surface pressure in excess of 1 bar is implied. Such a large volume of CO_2 probably cannot be accounted for in reversible sinks (frost, adsorbed CO_2, etc.), and the rate of loss to space of CO_2 is effectively negligible. A reasonable way to sequester this CO_2 is through formation of carbonate rocks at the martian surface.

Conditions will be most favorable for formation of carbonate rocks on Mars if liquid water is present. While pure liquid water is thermodynamically unstable at the surface in the present martian climate, there is abundant evidence for the action of liquid on the surface early in martian history. There are a number of locations on the martian surface where liquid water was apparently ponded early in the planet's history, albeit for undetermined periods of time. Sediments preserved in such deposition basins would be prime candidates for sites of martian carbonates. If carbonates are found in such sediments, they would preserve a record of the conditions on Mars when the climate was warm and wet. They would indeed be the final resting place of the CO_2 that made Mars warm and wet.

There is further evidence for martian carbonates. Trace amounts of carbonate have been found in SNC meteorites. In fact, there is evidence that these carbonates may have formed by sequestration of atmospheric CO_2. Carbon isotope ratios in them differ from the SNC whole-rock carbon ratios, but are like the isotopic ratios in the martian atmosphere.

Sampling objectives for study of martian carbonates include (1) confirmation of the presence of carbonates on Mars (if not already accomplished by Mars Observer); (2) estimation of carbonate abundance vs. time in the martian sedimentary record; (3) determination of the isotopic composition of carbonate in order to determine the source of the carbon and the temperature of precipitation; and (4) investigation of details of carbonate mineralogy in order to infer the environment in which the deposition took place.

Locating carbonates on Mars may be simple, but on the other hand may turn out to be a considerable challenge. Small amounts may be present in wind-distributed soil. Such carbonates, while certainly useful, would not satisfy all the goals stated above, since their provenance would be unknown. A much more attractive strategy would be to target ancient sediments likely to have been laid down in liquid water. Such sediments could be sampled directly at the surface where exposed by aeolian erosion, fluvial erosion, or cratering. They could also be cored. Because of the high priority of locating carbonate deposits and the possible difficulty in doing so, the rover should have at least a crude onboard analytical capability that can detect, for example, high carbon abundances in acquired cores or surface samples. These materials would then be specifically subsampled for return to Earth, as return of entire samples may exceed sample return mass limitations. Only small amounts of carbonate ($\gg$ 1 g) are required for isotopic studies. However, larger amounts, on the order of several grams per subsample, are needed for identification of carbonate mineralogy and characterization of petrographic relationships with other sediments present. Acquisition of carbonate samples from more than one sedimentary unit and with more than one age would be highly desirable.

Atmosphere

Atmospheric sampling is of fundamental importance for an understanding of martian climate and volatile evolution. The basic composition of the martian atmosphere is known from Viking measurements. However, the detailed isotopic composition of the atmosphere, particularly of elements such as noble gases present only in trace amounts, is incompletely known. Essentially nothing is known of the composition of the ancient martian atmosphere. Isotopic studies of both present and ancient atmospheric samples have considerable potential for illuminating the outgassing history and total volatile abundance on Mars.

The goal for sampling of the present atmosphere is simply to obtain a single, unfractionated sample of the martian atmosphere that is massive enough to permit multiple analyses of its detailed composition. A sample of the order of 10^3 cm^3 at ambient martian temperature and pressure should suffice for this purpose. It is also very important to attempt to obtain samples of ancient martian atmospheric gases trapped in rocks. Some information about the composition of the early atmosphere (for example, carbon isotope ratios) could be inferred from samples such as the carbonates discussed above. A more attractive source of paleoatmospheric information may be gases trapped in glasses formed by impact events. Such gases have played a key role in identifying Mars as the likely source of the SNC meteorites. However, the shock ages of the SNCs are relatively young, and the atmospheric composition indicated is very much like that of the present martian atmosphere. An effort should be made to locate and sample shocked rocks that can be identified clearly as ejecta from very ancient craters. Such samples would maximize the changes of obtaining small but useful samples of ancient martian atmosphere.

Soil

The martian soil is the product of weathering of martian rocks; that is, of reaction of martian rocks with volatiles. As such, it preserves a substantial record relevant to the inventory and history of martian volatiles. A number of processes may lead to initial formation of martian soil. One is volcano-ground ice or volcano-ground water interaction. For example, eruption of basaltic lavas into a water or ice-rich environment can lead to production of large amounts of palagonite. The spectral properties and elemental composition of palagonite provides a good fit to our present knowledge of these characteristics for martian soils. Massive hydrothermal alteration could also take place by impact heating of water or ice-rich materials. In either of these cases, hydrated silicates could be a significant reservoir for martian H_2O. Soil might also be formed by gradual weathering of igneous rocks under ambient surface conditions, although the rates for such reactions are likely to be low. Stable isotope studies of weathered materials, combined with knowledge of the composition of other volatile reservoirs, should permit investigation of weathering temperatures. If weathering processes have changed through time, such changes may be indicated by the compositions of soils of varying ages.

Once a soil has been formed in a given location, a number of types of reactions can act to alter it. For example, liquid water can percolate through it, leaching soluble salts at depth and depositing them near the surface. This may be the formation mechanism for the "duricrust" observed by Viking. A host of other reactions involving dissolved species can take place as well, resulting in complex vertical profiles of various sulfates, oxides, etc. Ultraviolet photochemistry may play a major role in controlling surface chemistry, perhaps producing the peroxides and superoxides that seem to be present. Other surface chemical reactions with major and minor atmospheric constituents can cause significant alteration of microscopic surface layers. All of these reaction products preserve some evidence of the process by which they formed and the volatiles involved in their formation. And again, cosmogenic nuclide profiles will provide information about soil deposition rates, erosion rates, and changes in volatile content.

The primary sampling objectives for martian soil are (1) to determine the mineralogy of soil materials, (2) to determine vertical profiles of salts and various other constituents, (3) to determine vertical profiles of cosmogenic nuclides, and (4) to investigate microscale surface alteration of rocks. Because much of the near-surface martian soil has probably been redistributed over the planet's surface by winds, the first objective could be largely achieved by acquisition of a small (a few grams) "grab sample" of soil virtually anywhere on the planet. The second and third objectives, however, require coring to depths of ~1–2 m. These cores could be returned intact or subsampled at intervals of several centimeters, with individual subsamples of a few grams each. Samples intended for cosmogenic nuclide studies should be subjected to the same kind of radiation control and monitoring as cited above for polar cores. Finally, an effort should be made to collect some rock samples for which microscopic layers exposed to sunlight and the martian atmosphere for long periods are carefully preserved. All returned soil samples should be maintained at temperatures no warmer than the warmest temperature experienced on Mars, in order to ensure preservation of any metastable phases that might be present.

EXOBIOLOGY

This session focused on the possibility of the development of life on Mars. The session included invited talks by H. P. Klein, A. Banin, D. Des Marais, E. Friedmann, and G. Levin, and contributed talks by J. Oro, C. Gehrke, and D. Cadenhead.

Other than the Earth, Mars remains the planet with the most interest to those researching the origin of life and contemplating its distribution in the universe. While the cold, dry environment on Mars is inhospitable to Earth life forms, it is the only other planet in the solar system on which the quintessential molecule of life, H_2O, undergoes cyclic processes and may even exist, albeit rarely, in the liquid form. It is this observation that has driven interest in searching for extant life on Mars.

Perhaps even more intriguing, however, is the possibility that early in its history Mars may have had a climate much more conducive to life than the present cold desert conditions. The geological and geochemical studies of Mars, reviewed previously, have strongly indicated that at one time Mars had liquid water on its surface—a stable and ample supply with respect to the needs of biological systems. This scenario is consistent with, and is supported by, atmospheric models that suggest that Mars' initial atmosphere may have consisted of several bars of carbon dioxide. Modeling studies suggest that this warm, clement epoch on Mars could have lasted on the order of several hundred million to a billion years.

On Earth, the oldest fossil evidence of life dates back to 3.5 b.y. ago and, by that time, there was already a fair degree of biological sophistication and diversity. The origin of life was probably much earlier, but the absence of a suitable fossil record prevents that determination. It is entirely possible, then, that life also arose on Mars during an early clement epoch. Subsequent planetary evolution, however, seems to have maintained habitable conditions only on the Earth. The record of the origin and early evolution of life on Earth has been obscured by extensive surface activity. On Mars the situation is quite different and large fractions of the surface date back to this early time period. Hence, it is entirely possible that, even if no life exists on Mars today, Mars holds the best record of the chemical and biological events that led to the origin of life and its early evolution.

Thus, for exobiology, Mars has threefold interest:

- chemical evolution and the possible origin of life;
- a putative early biological period under clement conditions;
- the possible survival of life in the present cold dry conditions.

Each of these scientific interests has implications for the amount and method of sample acquisition as well as selection of the sites from which the samples are to be taken. Therefore, one of the first objectives of the Exobiology session of the workshop was to prioritize and develop the scientific base for these exobiological goals. The following prioritization, suggested by Klein at the workshop, has emerged with broad support among exobiologists.

Priority 1: Chemical Evolution

The science questions in this category are based directly upon the Viking results. It is clear that there are significant questions that deal with the prospects for chemical evolution on Mars. The key to understanding chemical evolution on Mars is to understand the environments, both past and present.

Questions relevant to present environments include the nature of the oxidizing soil and the apparent absence of organic material. An intriguing aspect of the Viking biology results is the indication that the presence of water destroys the oxidizing power of the martian soil. Thus, in water-rich locations, it is possible that organic material will be present at the surface.

Questions relevant to past environments include the nature of sedimentary materials that appear to have been deposited in water. Of particular importance is the question of the presence or absence of carbonate deposits on Mars. Carbonate deposition on Earth is often enhanced by biological activity. Ancient martian deposits of organic material, if they exist, are also of interest.

Another important aspect of early Mars, which is relevant to the comparison to early Earth and the history of chemical evolution on both planets, is the presence of clays on Mars. Clays play a dominant role in some current theories for the origin of life.

Understanding the geochemical cycling of the biogenic elements (C, H, N, O, P, S) and their compounds (e.g., CO_2, H_2O, NO_x) in the early Mars, as recorded in the martian sediments, could provide useful tools in understanding the degree and direction of chemical evolution on that planet. Isotopic signatures are used in understanding the early Earth and the interaction between the biological and abiological chemical cycles. Of primary interest is the fractionation of the heavy stable isotope of carbon, ^{13}C, with respect to the common isotope, ^{12}C. Biological incorporation of CO_2 involves preferential selection of the lighter isotope, as a result of both thermodynamic and kinetic fractionations that occur during metabolic and biosynthetic reactions. In sediments from the Earth there is a distinct difference between the isotopic composition of carbonate carbon and that of organic carbon. The pattern of isotopic variation among hydrocarbons of increasing carbon number can be used to infer the nature of their formation, including abiotic processes.

Sulfur is a key biogenic element comprising approximately 0.1% dry weight of organic material. Biological cycles of sulfur, including the reduction of sulfate to sulfide in anaerobic environments and the oxidation of sulfides in aerobic environments, have distinct isotopic effects on the relative concentrations of ^{34}S and ^{32}S. The tracking of these isotopic changes in Earth's fossil record seems to be correlated with major changes in the atmosphere of the planet and in the biogeochemical cycling of S. Furthermore, the soil of Mars is known to be rich in S, in forms that may be, or have been, available to biology. Isotopic information from H and N are also potentially of significance in tracking the history of martian volatiles by geochemical analysis of the sediments. Variation in $^{15}N/^{14}N$ on Mars is particularly interesting because it is believed that the isotopic ratio of atmospheric N has varied monotonically with time due to atmospheric escape, enriching the heavier isotope. Hence, the N isotopic ratio of organic material or nitrates in the martian sediments may reflect the time of incorporation.

Priority 2: Past Life

While there is no direct evidence for past life, the Viking results lead to reasonable speculations that at one time life may have existed on Mars. Searching for fossil evidence for this past life would be analogous to studying the Earth's earliest biosphere, and could build upon the techniques and approaches developed in that discipline. The fossil evidence of early life on Mars might include organically preserved material, trace microfossils, microstructures and chemical discontinuities indicative of life, isotopic and chemical signatures of metabolic activity, and biological inorganic deposits. In addition to the search for direct traces of early life, the study of sedimentary carbonate deposits and clays would also be relevant to understanding the early Mars environment and the biological history of that planet. There are many geological features on Mars that date back to the early times, when biological activity might have been active.

Priority 3: Present Life

While the results of the Viking biology experiments have been mostly interpreted to indicate that there is no life on Mars at the present time, this interpretation is not unanimous. There continues to be speculation that there may exist life on Mars at the Viking lander sites or in isolated niches in which conditions are significantly different from the average dry desert conditions.

SAMPLING SITES AND STRATEGIES

H. Masursky and D. Scott reviewed work currently being done on potential landing sites for Mars Rover Sample Return missions. A number of sites have been chosen for study, and a variety of factors were taken into account in their choice. Some sites are relatively simple and uniform, being representative of major components of the planet, such as young lava plains. Others are more complex, at which a variety of materials of different origin and age might be available for sampling. Masursky showed, for example, that at sites near Mangala Valles different aged plains, the cratered uplands, fluvial deposits, and possible ignimbrites could all be sampled with a vehicle that could rove for about 100 km. Other sites discussed were at Kasei Valles, Olympus Mons, and the north and south poles. Implicit in the selection of most of the nonpolar sites was a desire to obtain the maximum variety, both in terms of the types of materials and their ages.

Different philosophies for choice of landing sites were propounded by G. Neukum and E. King. Neukum suggested that we should go to simple, uniform sites so that there is no ambiguity in the source of the rocks samples. His primary concern is to ensure that the absolute ages of the samples can be used to calibrate crater ages. For this purpose the first mission should go to a relatively young site, preferable on an extensive, uniform, lava plain. Subsequent missions should be chosen to span the geologic record. King proposed an entirely different strategy. He suggested that the earliest part of Mars' history is the most interesting. Conditions were warmer and wetter then than during most of the subsequent history, and the prospects for the development of life were far greater. Furthermore, since we may already have samples of the young lava plains in the SNC meteorites, sites on those units should have lower priority. He suggested that Hellas basin ejecta would be an ideal sample since it is of great areal extent and age, it probably contains a variety of rocks from varying depths within the crust, and is likely to contain evidence of volatile interaction.

The capabilities needed at Mars to support sample return were also discussed. R. Singer discussed the use of remote sensing, in particular visual and infrared spectrometry. He pointed out that only a small mass of sample is likely to be returned from a sample return mission. It is imperative therefore that analytical capability be available on the surface to search for rocks and soils of greatest compositional interest and variety. Visual and infrared spectrometry, while lacking the specificity of some other techniques, is ideal for this purpose because of the range at which it can operate. Spectrometry is also useful for characterizing potentially unstable samples before they are subject to the thermal and physical shocks during return. The technique can also be used from orbiters so that the distribution of different rock types sampled can be determined not only locally at the sample site but over the entire planet.

It is clear that more precise analyses than are possible with visual and infrared spectrometry will also be needed to support sample acquisition. Likely candidates are XRF and gamma-ray spectrometry, discussed by L. O. Yin and J. Trombka, and alpha proton X-ray spectrometry, discussed by T. Economou and A. Turkevich.

A variety of tools and packaging devices will be needed. J. Allton reviewed the Apollo experience. Drills, drive-tubes, rakes, scoops, and tongs were all used during Apollo and samples collected by each tool were all utilized. In general, the samples with the highest allocations per gram were those rich in fragments in the 1–10 mm size range. A major problem was encountered in sealing the sample boxes, partly because of the dusty conditions under which sealing took place. Sealing at Mars is more crucial because of the likely presence of volatiles, and may be even more difficult than on the Moon because of the dusty conditions. B. Clark discussed what tools might be needed at Mars. He suggested that drills would be more important at Mars than on the Moon because of the desire to get beneath the weathering rind on rocks, the desire to get profiles through sediments and soils, and the desire to preserve the volatiles in the sampled materials. Uniformly shaped drill cores can also be conveniently and compactly packaged for return to Earth.

SUMMARY OF SAMPLING RECOMMENDATIONS

SNC Meteorite—Mars Connection

- any samples with enough oxygen to permit accurate determination of ^{16}O, ^{17}O, and ^{18}O and the establishment of a Mars fractionation line

Accretion, Core Formation, and Primordial Atmospheric Outgassing

Types of Samples:
- mantle samples
- enough basalts to populate siderophile element versus lithophile element diagrams
- atmosphere sample with adequate C, N, O, and noble gases
- rocks sampling different chemical and isotopic reservoirs

Sampling Locations:
- fresh volcanic suites, probably in northern hemisphere

Sample Masses:
- approximately 1 g of each fresh rock sample
- approximately 10^{-1} cc STP of atmosphere

Magmatic History

Types of Samples:
- variety of unweathered basalts for petrology, geochemistry, chronology
- primitive (high Mg/Fe) fine-grained or glassy basalts for determining primary magma composition
- ancient crustal rocks, unweathered if possible
- mantle samples
- soil samples, for obtaining volcanic and impact glasses
- dust

Sampling Locations:
- volcanic suites of various ages, especially 2–4 b.y.
- ancient highlands terrain

Sample Masses:
- ~1–5 g of each fresh rock sample, depending on grain size
- ~0.5 g of dust from each landing site
- ~0.5 g of each sample of volcanic or impact glass

Surface Modifying Processes

Types of Samples:
- ejecta from old impact craters
- ejecta from young impact craters
- dunes
- Memnonia mantle deposits
- highland "lake"

Sampling Locations:
- ancient highland crust
- young lava plains
- northern sand sea
- Memnonia
- highland region

Sample Masses:
- approximately 5 g

Climate, Atmosphere, and Volatile Inventory

Types of Samples:
- ground ice samples (probably requires coring)
- polar layered deposit cores
- carbonate samples
- martian atmosphere
- soil core

Sampling Locations:
- ground ice: latitudes above 40°–50°
- polar layered deposits: latitudes above 80°
- carbonates: ancient sedimentary basins, perhaps associated with valley systems in ancient cratered terrain
- atmosphere: anywhere
- soil: many locations would be acceptable

Sample Masses:
- ground ice and carbonates: a few grams per sample
- polar deposits: subsampled cores, a few thin vertical subsamples 5–10 g/each, plus one contiguous subsample 100 cm long (100 g)

- atmosphere: 1000 cm^3 at ambient P and T
- soil: continuous core or subsampled core, with subsamples approximately 1–2 g each every few cm

Exobiology

Types of Samples:

- water-lain sedimentary material, particulary those that may contain organic material
- carbonates and other precipitates and salts, again with emphasis on those that may contain organic material
- clay and water-altered materials (minerals)

Sampling Locations:

- sites where water was present in the first billion years of martian history. Candidate sites have been identified by geomorphological analysis
- sites were water activity may be occurring at the present, probably associated with concentrated brine solution resupplied by diffusion from below
- sites near the polar regions where water is being seasonally deposited and sublimed as ice

Sample Masses:

- approximately 1–10 g each
- about 5–10 samples within each core or site

AFTERWORD

While the workshop was successful in outlining the scientific problems to be addressed by a Mars Rover Sample Return mission and the natures, masses, surface locations, collection, and curation issues associated with addressing those problems, it did not succeed in defining the strategy an actual mission would follow in collecting and retaining samples at a specific site. Accordingly, the following recommendations were made to the Mars Rover Sample Return Science Working Group.

Recommendation 1

- Assemble a small (less than ten-person) team to develop optimum sampling strategy
- Select a few diverse candidate landing sites on Mars
- Product
    - Science questions addressed
    - Science questions ignored
    - Sample types
    - Sample selection
    - Sample curation

Recommendation 2

- Assemble a small (less than ten-person) team to develop optimum sampling strategy
- Select a few diverse candidate landing sites on Earth
- After strategy development, walk scientists and engineers over terrain, see what you *actually* could get
- Product
    - Science questions addressed
    - Science questions ignored
    - Sample types
    - Sample masses
    - Sample locations
    - Sample collection
    - Sample curation

ABSTRACTS

N89-18289

THE MARS OBSERVER DATABASE; Arden L. Albee, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125

Mars Observer will study the surface, atmosphere, and climate of Mars in a systematic way over an entire martian year. The observations of the surface will provide a database that will be invaluable to the planning of a future Mars sample return mission.

Mars Observer is planned for a September 1992 launch from the Space Shuttle, using an upper-stage. After the one year transit the spacecraft is injected into orbit about Mars and the orbit adjusted to a near-circular, sun-synchronous low-altitude, polar orbit. During the martian year in this mapping orbit the instruments gather both geoscience data and climatological data by repetitive global mapping.

The scientific objectives of the mission are:

- Determine the global elemental and mineralogical character of the surface material;
- Define globally the topography and gravitational field;
- Establish the nature of the magnetic field;
- Determine the time and space distribution, abundance, sources, and sinks of volatile material and dust over a seasonal cycle;
- Explore the structure and aspects of the circulation of the atmosphere.

The science investigations and instruments for Mars Observer have been chosen with these objectives in mind. These instruments, the principal investigator or team leader and the objectives of the investigation are as follows:

Gamma Ray Spectrometer (W. Boynton)

1. Determine the elemental composition of the surface of Mars with a spatial resolution of a few hundred kilometers through measurements of incident gamma-rays and albedo neutrons (H, O, Mg, Al, Si, S, Cl, K, Fe, Th, U).
2. Determine hydrogen depth dependence in the top tens of centimeters.
3. Determine the atmospheric column density.
4. Determine the arrival time and spectra of gamma-ray bursts.

Mars Observer Camera (M. Malin)

1. Obtain global synoptic views of the martian atmosphere and surface to study meteorological, climatological, and related surface changes.
2. Monitor surface and atmosphere features at moderate resolution for changes on time scales of hours, days, weeks, months and years.
3. Systematically examine local areas at extremely high spatial resolution in order to quantify surface/atmosphere interactions and geological processes.

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Visual and Infrared Mapping Spectrometer (L.Soderblom)

1. Produce km-resolution mosaics of the martian surface in 320 spectral channels for the purpose of identifying mineralogical and chemical units, studying the distribution of surface volatiles and understanding the physical structure of the regolith.
2. Produce a regional map of the martian surface at 10 km resolution in 10 wavelengths.

Thermal Emission Spectrometer (P. Christensen)

1. Determine and map the composition of surface minerals, rocks and ice.
2. Study the composition, particle size, and spatial and tempora distribution of atmospheric dust.
3. Locate water-ice and carbon dioxide condensate clouds and determine their temperature, height and condensate abundance.
4. Study the growth, retreat and total energy balance of the polar cap deposits.
5. Measure the thermophysical properties of the martian surface (thermal inertia, albedo) used to derive surface particle size and rock abundance.
6. Determine atmospheric temperature, pressure, water vapor, and ozone profiles, and seasonal pressure variations.

Pressure Modulator Infrared Radiometer (D. McCleese)

1. Map the three-dimensional and time-varying thermal structure of the atmosphere from the surface to 80 km altitude.
2. Map the atmospheric dust loading and its global, vertical and temporal variation.
3. Map the seasonal and spatial variation of the vertical distribution of atmospheric water vapor to an altitude of at least 35 km.
4. Distinguish between atmospheric condensates and map their spatial and temporal variation.
5. Map the seasonal and spatial variability of atmospheric pressure.
6. Monitor the polar radiation balance.

Radar Altimeter and Radiometer (D. Smith)

1. Provide topographic height measurements with a vertical resolution better than 0.5% of the elevation change within the footprint.
2. Provide RMS slope information over the footprint.
3. Provide surface brightness temperatures at 13.6 GHz with a precision of better than 2.5K.
4. Provide well sampled radar return wave forms for precise range corrections and the characterization of surface properties.

Radio Science (G.L. Tyler)

Atmosphere

1. Determine profiles of refractive index, number density, temperature, and pressure at the natural experimental resolution (approx. 200m) for the lowest few scale heights at high latitudes in both hemispheres on a daily basis.
2. Monitor both short term and seasonal variation in atmospheric stratification.
3. Characterize the thermal response of the atmosphere to dust loading.
4. Explore the thermal structure of the boundary layer at high vertical resolution (approx. 10m).
5. Determine the height and peak plasma density of the daytime ionosphere.
6. Characterize the small scale structure of the atmosphere and ionosphere.

Gravity

1. Develop a global, high-resolution model for the gravitational field.
2. Determine both local and broad scale density structure and stress state of the martian crust and upper mantle.
3. Detect and measure temporal changes in low degree harmonics of the gravitational field.

Magnetometer (M.Acuna)

1. Establish the nature of the magnetic field of Mars.
2. Develop models for its representation, which take into account the internal sources of magnetism and the effects of the interaction with the solar wind.
3. Map the martian crustal remanent field using the fluxgate sensors and extend these in-situ measurements with the remote capability of the electron-reflectometer sensor.
4. Characterize the solar wind/Mars plasma interaction.
5. Remotely sense the martian ionosphere.

The Mars Observer project will utilize data standards and all mission data will be stored in a project database. Investigators and analysts will access the database to participate in the planning process and to provide status and higher-order data products. This process will facilitate the use of the Mars Observer database by the planetary science community.

THE SAMPLE SITE ON MARS/ Arden L. Albee, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125

The first two days of this workshop are to be devoted to a summary of our knowledge of Mars-- its formation; the evolution of its interior and tectonics; the impact, aeolian, volcanic, fluvial, and volatile-related processes on its surface; the atmosphere, weather, and climate; and the likelihood of life, now, or in the past. These presentations lead naturally into a consideration of the questions that remain to be answered and to a discussion of the numerous sample types and sampling sites required to answer the wide variety of questions. This part of the workshop is very important, but it is even more important to discuss in great detail how to choose a single sample site on Mars.

It is quite possible that only a single Mars sample return, hopefully with a backup, will be initiated. Even if a series of missions should be approved initially, the study of the first Mars sample must provide a significant scientific advance toward our understanding of Mars and the inner planets. Thus, it is tempting to choose a complex site where a variety of questions can be addressed by samples collected by a 100 km rover traverse. However, it can be argued that the prime sampling objective of a first mission should be to collect both fresh and weathered samples of the most abundant types of materials in the near vicinity of the lander.

Numerous candidate landing sites have been studied in the high-resolution Viking images. Some sites are totally underlain by a single bedrock unit, while others contain several units in close proximity. Missions with a prime objective of sampling several units are more demanding in terms of landing location error, mobility, and sampling capability. Of course any site on Mars will contain a variety of wind-blown and impact-derived debris, which will increase the probability of sample variety. Samples of atmosphere gases and soil volatiles can also be collected at any site and will provide information about atmospheric/surface interactions and on the extent of planetary degassing and retention.

On the Viking images it is possible to identify relatively-young volcanic rocks that underlie areas of size similiar to the landing error ellipse. Study of the orbital images of some such areas indicates that a mobility of several kiliometers should be sufficient to travel from any random point in a given landing ellipse to the nearest outcrop or young crater that might provide unweathered material. From geochemical, petrological and age-dating studies of such volcanic rocks, we expect to be able to decipher the thermal history of the martian mantle, the extent of its chemical differentiation, and the process involved in near-surface chemical fractionation. We can expect to establish more narrow limits on the bulk composition of the planet; to determine the fundamental properties of that region of the solar nebula from which Mars accreted; to determine the ages of lavas erupted onto the surface (which will in turn provide ground truth for ages based on the cratering statistics, allowing us to extend these ages to the rest of Mars and by inference to the inner planets); and to establish the nature of martian volcanic gases and the extent to which these gases have contributed to building up the martian atmosphere.

Based on such considerations, I suggest that the first sampling mission to Mars should be targeted to a landing site within a large (> 50km diameter), relatively-young (by crater counts), volcanic unit, one that can be mapped into the regional geologic picture (based on the highest resolution Viking images). Collection from adjacent units should not be a prime objective in designing the mission. In addition the site should be at low altitude, near-equatorial and "hazard-free". At this workshop it is important that we focus on the need to study and compare those few sites that do meet such criteria.

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N89-18290

HOW SUCCESSFUL WERE THE LUNAR SAMPLING TOOLS?: IMPLICATIONS FOR SAMPLING MARS;

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Like the Mars Sample Return endeavor, the Apollo lunar-sample program began with definition of strategy for sample collection and of scientific requirements for sampling hardware design. A review of the pre-mission recommendations as they influenced hardware design and compared with the samples obtained and actually used may be helpful. Influential and detailed pre-mission criteria resulted from two mid-1960's summer studies involving the scientific community (1,2). Pre-mission strategy and requirements followed through the actual allocation of samples will be restricted to the Geology and Geochemistry Groups, since these groups remain interested in lunar samples today. The Geology Working Group was interested in characterizing the material underlying the plains and in the processes responsible for the fine structure of the surface. A more global view was taken by the Geochemistry Group, whose list of scientific inquiries included: comparing the chemical and isotopic composition of the Earth and Moon, comparing the time scale for lunar events to those established for Earth history, determining lunar evolution by establishing relative ages of major lunar events, establishing the Moon as a primitive or differentiated body, determining the gross composition of the lunar surface as a whole, establishing the relative roles played by internal and external processes in shaping present topography, and finally, surveying the Moon's resources such as water, oxygen, and energy (1).

In seeking answers to these questions, the following strategies were devised. The highest priority was to return some sample from each landing site. To assure some kind of sample return, a "grab" or "contingency" sampling procedure was proposed. If given time to make selections, samples from dust to rocks in size and from surface and subsurface were desired. Numerous small samples were preferred over fewer larger samples. Fragments of a few centimeters diameter were considered adequate for petrographic studies. Astronauts were encouraged to use judgement in sample selection and to try and obtain at least one of each type, including exotic samples. A statistical or grid method was considered very poor strategy. Samples collected and returned were to be free from chemical contaminants, some were to be aseptic, and some were to be maintained under lunar environmental conditions.

The Geology Group specified the types of hand tools needed for sample collection. They viewed sampling as a very precise operation requiring the astronaut to have "down on the hands and knees" flexibility and regarded documentation as extremely important. On the other hand, The Geochemistry Group viewed the sampling process more broadly, as the gathering of a variety of samples under very clean conditions. Consequently, they defined which materials would be acceptable for touching lunar samples.

Specific hand tools under development in early 1967 included 3 core tubes, 3 aseptic sample collectors, scriber-hand lens-brush, tongs, 200 sample bags, scoop, hammer, and a bio-science sample collector (3). Drive tubes were thought to be useful for obtaining samples representing an entire profile from greater depths than would be possible with a trench. A 3-meter drill was planned for later missions. Suggestions for sample containers ranged from hermetically sealable teflon bags (biological barriers) to rigid containers capable of maintaining the lunar environment. Requirements for the Apollo Lunar Sample Return Container (ALSRC) included retention of 10^{-6} torr vacuum, retention of interior temperatures less than 65 °C, and construction of stainless steel (preferred) or aluminum.

Materials for hand tools and containers were recommended to minimize or eliminate contamination from Pb, U, Th, Li, Be, B, K, Rb, Sr, noble gases, rare earths, micro-organisms, and organic compounds. The main structural materials were aluminum alloy 6061 and 300 series stainless steel. Teflon was the only acceptable plastic, although Viton was acceptable for backup, exterior seals. MoS_2 was agreed upon for a lubricant, as was use of soft indium metal for sealing surfaces.

The lunar surface hand tools used to collect samples on the Moon and the types of samples each tool collected are given in Table 1. Curatorial data for sample types, roughly corresponding to those in Table 1, are shown in Figure 1. For each sample type, the total number of sub-samples allocated for scientific research, the average weight of the samples (as collected on the Moon), and the number of sub-samples allocated per gram of collected sample are displayed. The large number of allocations indicates that the lunar samples were studied intensively. The number of sub-samples allocated per gram of collected sample indicates relative scientific interest in different sample types. A larger number of smaller, more specific samples were taken on later missions; hence, the Apollo 15-17 data are set apart from Apollo 11-14 data in the chart. The rake sample rocks (taken only on Apollo 15-17) were compiled separately from rocks which were selected individually to see what effects random selection had on sample usefulness. The rake smaller sample size influences the "interest index" more than the selection process. Increased petrologic variability per unit weight attracted greater scientific "interest" as exhibited by the small fragments extracted from soils (these 1 to 10 mm size fragments were extracted in the laboratory from bulk soils). "Interest" in cores is enhanced, because they possess the added variability of depth. Yet, 8 core tubes remain unopened, because cores did not fulfill the expectations of definitive stratigraphy.

Several lessons can be illustrated by specific tools. The evolution of drive tubes from narrow 2-cm diameter, thick-walled tubes (used on Apollo 11, 12 and 14) to 4-cm diameter, thin-walled tubes used on Apollo 15, 16 and 17) is an example of the improvements made possible during multiple missions. The original Apollo 11 drive tube was designed to work in fluffy soil; thus, only 50% of the relatively dense lunar soil was recovered, and the core was distorted (4). The final configuration resulted in nearly 100% recovery with little distortion (5). The surface samplers (Contact Soil Sampling Devices) were designed to collect the upper 100 μm or the upper 1 mm of soil. It was over 2 years after the mission before these particularly specific samplers were opened because interest in them waned. Both core tubes and surface samplers were difficult to open in the laboratory. The ALSRC's were constructed with one indium and 2 Viton seals. They were closed on the lunar surface. Interior container pressures measured upon return to the laboratory (Table 2) indicate that these seals were not reliable in the lunar environment. Also, choice of indium as a sealing material interfered with siderophile analyses of samples.

Conclusions about sampling devices: unreliable container seals, the need to redesign the drive tubes, and difficulty in opening samplers suggest that 1) Mars sampling strategy be viable if seals fail, 2) tools be simple (drill corer necessary?), and 3) the curation environment (low P, low T, zero-G ?) be defined early so that laboratory handling can be a design requirement.

Conclusions about sample types: good use of small samples, intensive use of 1-10 mm soil fragments, lack of apparent core stratigraphy, and non-use of some cores indicate that 1) numerous small samples be collected, 2) fragments be concentrated by sieving soils, 3) sampling strategy be viable if core stratigraphy is not apparent, and 4) core samples be examined on the Martian surface to determine science value.

Table 1. HAND TOOLS USED TO COLLECT LUNAR SAMPLES

TOOLS	TYPE SAMPLE COLLECTED	MISSION
Contingency sampler	Surface soil & small rocks	11, 12, (14-17?)
Tongs	Particular rocks with shortest dimension <6 cm	All
Large scoop	Surface soil & small rocks	11, 12
Adjustable scoop	Surface & subsurface soil	12 - 17
Adjustable trenching tool (shovel)	Subsurface soil	12 - 17
Hammer	Pieces of large rocks, drive the core tubes	All
2-cm drive tubes	.5 m soil column	11, 12, 14
4-cm drive tubes	.5 m soil column	15, 16, 17
Drill	3 m soil column	15, 16, 17
Rake	Statistical sampling of fragments >1 cm	15, 16, 17
Surface samplers	Upper 100 um & upper 1mm of soil	16
Astronauts	Big rocks	All

Table 2. APOLLO LUNAR SURFACE RETURN CONTAINER PRESSURES MEASURED IN LABORATORY

MSN	S/N	PRESSURE (atmospheres)
11	1003	.0002
	1004	.0002 (7)
12	S	.00007
	D	.5 (8)
14	1006	.00008
	1007	1
15	1011	.00005
	1012	1
16	1009	1
	1010	.0001
17	1007	.0002
	1006	.00004 (9)

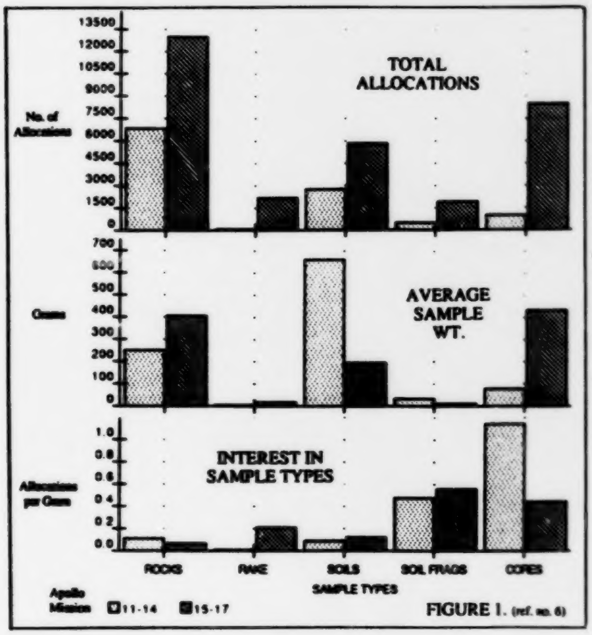

FIGURE 1. (ref. no. 6)

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N89-18291

SAMPLES FOR ESTIMATING PRIMARY VOLATILES IN MARTIAN MAGMAS AND ANCIENT ATMOSPHERIC PRESSURES ON MARS; A.T. Anderson, Jr., The University of Chicago

Inclusions of glass are likely to be present in phenocrysts in volcanic rocks from Mars, because these occur in volcanic rocks from both Earth and Moon. The usefulness of the inclusions depends upon their size and composition. The compositions of tiny inclusions may be modified by diffusion during growth of the enclosing crystal, the modifications increasing with melt viscosity (silica). Slow cooling results in crystallization and possible redistribution of volatiles, the effects increasing with decreasing silica. Primary volatile concentrations are best sought in inclusions larger than about 50 microns diameter in olivine or chromite crystals from quickly cooled basaltic scoria. Such crystals may be present in sands, but it would be preferable to extract them from individual rocks which could be dated and compositionally characterized. This would allow eventual understanding of the role of time and place in outgassing and volcanism on Mars. Analyses of volatiles in inclusions of more siliceous glass in non-basaltic rocks will reveal whether deep outgassing occurs and whether surface volatiles are recycled. Most volcanic crystals contain inclusions, but large inclusions can be uncommon. In the case of terrestrial basalts sample masses of several hundred grams are generally sufficient.

The vesicularity and vesicle size/space distribution in solidified lavas can be used to estimate pressures of emplacement. Flow emplacement processes are generally complex and generally render the vesicularity method subject to too many uncertain initial assumptions. However, the vesicle size distribution is more robust. It can first of all reveal whether the flow emplacement was simple and followed by bubble rise and coalescence. Because the eventual size distribution depends upon the probabilities of coalescence, multi-modal distributions result from an intially uni-modal distribution. The modes can be predicted and their shift from values predicted for coalescence without decompressive enlargement provides a means to measure the amount of decompression. Because of the reciprocal relation between volume and pressure, the shift in size is substantial so long as the overburden (atmospheric) pressure and lava-static pressures are comparable. The lava-static pressure is calculable from the depth within the lava, leaving the atmospheric pressure as the only unknown depending upon the size shifts. Tests with terrestrial lavas are in progress and yield good agreement between observation and theory. The study by Sahagian (1985) and Sahagian, Anderson and Ward (unpub.) was done by impregnating kilogram blocks of basalt with plastic, dissolving the rock and counting the plastic casts of the vesicles. Comparable samples from known heights within Martian lavas would be necessary.

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CONSTRAINTS ON MARS SAMPLING BASED ON MODELS OF BASALTIC FLOW SURFACES AND INTERIORS; J. C. Aubele and L. S. Crumpler, Dept. of Geological Sciences, Brown University, Providence, RI 02912

We assume that basaltic plains units on Mars are a dominant terrain type and, for future missions, will be a landing site of choice due to engineering or sampling constraints. Proposed rover/sample return missions will traverse, or at least photograph and sample, small-scale surface blocks and outcrops within large flow units. Actual contacts between rock types may be difficult to find or recognize for an in situ lander or even for a rover of limited range. However, the surface characteristics of the plains units, (blocks, cobbles, outcrops, dunes, and other surficial materials) will be visible, and may even act as limiting parameters to rover trafficability or lander sampling strategies. These surface characteristics can be interpreted in a geologic context if we understand the nature of degraded basaltic flow surfaces.

Recent field observation and numerical modeling of the pattern and origin of vesicle zones and joints in terrestrial basaltic flows [1] has resulted in increased understanding of the processes which affect flow surface morphology. This work has documented the ubiquitous occurrence of three vertical zones in basalt flows: (1) an upper vesicular zone; (2) a middle vesicle-free zone and (3) a lower vesicular zone. The upper vesicular zone is generally about one-half of the total flow thickness. Computer modeling of the development of these zones confirms that vesicle zonation is a result of the nucleation, growth and rise of bubbles in solidifying lava and can be expected to occur in all basaltic flows. Degradation of basaltic flows, therefore, will produce vesicular blocks until the erosional level reaches the central vesicle-free zone. In addition, observation of terrestrial basaltic flows [2] has shown that most thin (less than 10m thick) flows have a regular pattern of orthogonal joints in vertical section in which the spacing of joints increases with depth beneath the flow surface. Therefore, as a flow erodes vertically the degradational surface of that flow will be characterized by blocks of a size similar to the spacing of joints at that level in the flow. Generally, as a crude approximation, the joint spacing at a specific level in the flow will be roughtly equivalent to the depth from the primary flow surface to that level. As a basaltic flow degrades, the erosional surface will be characterized by a bimodal distribution of fines and blocks. The mode of the block size population is an indication of the depth to which that flow has been eroded.

Using these studies we have performed a preliminary analysis of the Viking lander sites [3]. If the rocks at the Viking lander sites are basaltic, and if the pits visible in lander imagery are vesicles, then certain basic assumptions can be stated regarding the geology of the sites. The natural degradation of a basaltic flow can result in a blocky surface. Impact disturbance of the surface may add some large blocks but is not required as a mechanism for generating the observed blocks on the surface. The general size of the block populations at both sites [4] indicate a flow disturbed by erosion to a depth of tens of centimeters. Blocks containing abundant vesicles could be from the upper vesicular zone. A few large blocks (greater than 1m), without vesicles, visible at both lander sites probably represent excavation by impact from some greater depth in the flow than has been reached by erosion.

SAMPLING AND MODELS OF BASALTIC FLOWS

AUBELE, J.C. and CRUMPLER, L.S.

These studies, and the new understanding of basaltic flow surfaces that they provide, also have implications for future Mars sample return missions. For example, trafficability is related to the abundance and size of blocks at the surface, which in turn is related to the depth of erosion of a basalt flow. Flows which have experienced disturbance of the surface to a deep level may be more difficult to traverse because modal block size will be larger. In terms of an *in situ* sample mission, a sample from near the surface of a basaltic flow will contain less mass per unit volume than will a sample from the vesicle–free interior. In other words, a sample collected from the top of the upper vesicular zone would be predominantly voids. Maximum mass per unit volume will occur in samples from the vesicle–free zone. In addition, basalt from the upper vesicular zone is frequently more microcrystalline than is basalt from the vesicle–free zone and consequently more difficult to characterize petrographically. For these and other reasons, optimal sampling of a basalt flow would require a sample from the vesicle–free zone. If basaltic flow structure on Mars is comparable to that on Earth, then this means a flow which has been eroded down to one–half its total flow thickness. But this type of surface cannot be easily traversed, in the event of a rover mission, because of its large blocks. One solution may be a landing site on a basalt flow of intermediate age with a surface disturbed by a few small impact craters which have excavated blocks from the interior of the flow.

In future work, we anticipate formulating a detailed model of the mechanics of formation of the interior structure (vesicle formation, vesicle zones, joint patterns) of basaltic flows, and the way in which this structure constrains the surface morphology of degraded flows. This model will then be used to (a) predict the surface properties of basaltic plains units which will act as limiting parameters to future Mars lander/sample return/rover missions, and (b) to construct models of basaltic surfaces by which the imagery and samples from future lander missions can be evaluated and interpreted.

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THE SOILS OF MARS; A. Banin, Dept. of Soil and Water Sciences, Hebrew University, P.O. Box 12, Rehovot 76100, Israel.

Soil on Mars can be defined as "The top non-consolidated layer of weathered and partly weathered rocks of the Martian lithosphere that is exposed to atmospheric effects". The Martian soil covers large portions of the planet surface as one "soil unit" (1), and constitutes a loosely-packed nonconsolidated porous body of very fine particles. Soil material appears to have been thoroughly mixed and homogenized on the global scale by dust storms. Evidences for homogeneity are: (a) the similarity of spectral reflectance fingerprints of large areas on Mars designated as the "bright" regions that appear to represent the more oxidized and weathered rock materials (1,2); (b) the similarity of phsical-mechanical properties of the soil in the two Viking landing sites (3,4,5), and (c) the almost identical bulk-elemental chemical composition of the fine soil studied in the two Viking landing sites (6,7,8).

These fine soil materials are major participants in present-day, planet-wide surface-atmosphere interactions through dust storm activity, volatile balances and land-forming processes. The volcanic history of Mars and the weathering conditions on its surface have left their fingerprints on the soil. Furthermore, the soil may hold clues to the processes that shaped the early history of Mars including abiotic evolution and the possibilities of primitive biotic evolution. Thus, soils are very appropriate candidates for sample-return from Mars, and, because of their spread on the planet's surface, can be an integral part of almost any Mars Rover/Sample Return (MRSR) mission. The current knowledge of the properties of the soil will be briefly reviewed in the following, and open questions that may be answered by thoroughly studying a returned sample will be outlined.

Morphological, Physical and Mechanical Properties: At the two Viking Lander sites a fine reddish soil material is surrounding and covering non-weathered blocks, boulders and cobble-sized rocks. Bulk densities of 1.2 to 1.6 g/cm^3 and low cohesion of $\leq$10kPa characterize the soil (3,4,5). Interparticle cementation by recrystalized salts (chlorides and sulphates) is causing crust and clod formation (5,6). Soil stabilization by salt migration shall be further studied as it relates to aeolian depositional rates and water movements in present-day Mars.

Chemical Composition: The soil analyzed by the two Viking Landers (6,7,8) is relatively rich in silicon and iron, low in aluminum and contains relatively high sulfur and chloride concentrations. Elements directly analyzed account for about 50% of the soil weight (6); if all the detected elements except Cl are assumed to be in their common oxide forms, the total accounts for about 90% of the soil weight (7). The remainder was attributed to: (a) compounds of the elements P, Mn, Cr and possibly Na, which could have been detected but could not be determined unambiguously by the Viking XRF instruments. The amount was estimated to be 2%. (b) Compounds of elements that could not be detected by the Viking XRF; these include water, carbonate, and nitrate, and may account for 8% of the soil's weight (7).

Assuming SNC meteorites are indeed Martian rocks, recent detailed analyses of these meteorites are invaluable in broadening our chemical data-base on Mars rocks and soils (9,10). A combination of the directly measured compositional average data for the Mars soil with SNC analyses is given in Table 1 as a proposed working model for the Mars soil chemical composition. In future studies of Mars this and other models shall be validated by detailed direct analyses. Furthermore, it shall be correlated with source-rock composition to clarify soil formation scenarios and climatological evolutionary pathways on Mars.

The presence of organic matter in the soil, a critical component in relation to exobiology on Mars, is still an open question. The Viking GCMS did not detect any organic material in the soil (11,12); the high redox potential of the soil, shown in the Viking biology experiments and depicted also by the abundance of ferric iron, may have caused the oxidative-decomposition of any organic matter synthesized in the soil or imported by meteorites. However, the Viking landers have sampled the top 0-10 cm of the soil and performed only four analyses. It is of great interest to extend the sampling to greater depths and to various locations where paleosoils may have been shielded from atmospheric and radiative effects and residual organic matter may have been preserved.

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Mineralogical Composition: The mineralogical composition of the soil has not been directly analyzed yet. Many candidate minerals have been proposed on the basis of various measured properties that are related to or affected by the soil mineralogy (13). On the basis of the chemical composition it was proposed initially (6,7) that the soil contains smectite clays mixed with kieserite, calcite and rutile. Thermodynamic modelling of the atmsophere-rock equilibria, gave somewhat conflicting results. One study (14) predicted the presence of only simple oxides, carbonates and silicate minerals mixed with soluble salts. Another study (15) suggested that the soil contains high proportion of smectite clays (mostly montmorillonite) mixed with other phyllosilicates (talc), quartz, hematite and anhydrite.

Spectral reflectance has been used to identify mineral components in the Martian soil. In the visible and near IR range (0.4-1.3 μm) the Martian reflectance spectrum (1,2) is characterized by absorbances due to ferric iron which is not present in a well crystalized environment. It can be simulated by the iron-rich montmorillonite clays (16), various amorphous iron oxyhydroxides (17,18) and by palagonite (19). Other candidate minerals that have been proposed on the basis of spectral evidence include talc and serpentine (20) and anatase (21).

Simulation of the main features of the Viking Biology experiments was achieved with iron enriched montmorillonite (22-26). However, it was also proposed that Viking Biology results can be explained assuming the presence of recent weathering products of mafic minerals in the soil (27).

In summary, we propose a mineralogical model for the Mars fine soil that includes as major components smectite clays adsorbed and coated with amorphous iron oxyhydroxides and perhaps mixed with small amounts of better-crystalized iron oxides as separate phases. Also present as accessory minerals are sulfate minerals such as kieserite ($MgSO_4 \cdot H_2O$) and/or anhydrite ($CaSO_4$), rutile (TiO_2), and maghemite (Fe_2O_3) or magnetite (Fe_3O_4), the last two as magnetic components. Carbonates may be present at low concentrations only (less than 1-2%). However, a prime question to be addressed by a MRSR mission shall be related to the mineralogical composition of the soil, and its spatial variability.

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Table 1. Average Chemical Composition Model of the Fine Martian Soil

Oxide	Selected Average Concentration %	Oxide	Selected Average Concentration %	Compound	Selected Average Concentration %
SiO_2	43.4*	K_2O	0.10**	SO_3	7.2*
Al_2O_3	7.2*	P_2O_5	0.68**	Cl	0.8*
Fe_2O_3	18.2*	MnO	0.43**		
MgO	6.0*	Na_2O	1.34**	CO_2	<2***
CaO	5.8*	Cr_2O_3	0.29**	NO_3	?
TiO_2	0.6*			H_2O	0-1†

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*Based on direct soil analyses by Viking XRF (6,8). **Based on SNC meteorite analyses (9,10). ***Estimated from LR simulations (24,28). †Varying content.

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THE RIDGED PLAINS AS A POSSIBLE LANDING SITE FOR THE MARS SAMPLE RETURN MISSION.

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Differences in the shape and density of crater size-frequency distribution curves have been interpreted as indicators of different impactor populations (1) (Fig. 1). Within the inner solar system two production populations are seen. The signature of the first is recorded in the heavily cratered regions of the moon, Mercury, and Mars and displays a multi-sloped distribution curve which cannot be described by a power law function at all crater diameters. The signature of the second population is seen in the lightly cratered lunar and martian plains, where the size-frequency distribution curve can be approximated by a power law function of -3 differential slope in the 8- to 70-km diameter range. Based on data obtained from the Apollo lunar samples and crater flux estimates, the first population is believed to have been emplaced during the period of heavy bombardment, which, at least on the moon, ended about 3.8 BY ago. The second population has dominated the cratering record since that time and is commonly assumed to be due to comets and asteroids.

The objects responsible for the period of heavy bombardment may have been left over accretional remnants (2), pieces of a gravitationally disrupted planetismal (3), or comets (4). Dynamical calculations for objects with most of these origins indicate that the end of heavy bombardment was approximately simulataneous within the inner solar system (3, 4). However, computer simulations indicate that if accretional remnants were responsible for the cratering record during this period, the end of heavy bombardment may have been extended at Mars by up to a billion year over that at the moon (2). Since a major assumption in the derivation of martian absolute age chronologies is the simulataneous termination of heavy bombardment at the moon and Mars (5, 6), the dating of the end of heavy bombardment is of great scientific interest to martian researchers.

The ridged plains units of Mars are primarily equatorial regions characterized by flat plains transected by numerous wrinkle ridges. The moderately cratered surfaces of these units shows a crater density between that of the heavily cratered southern uplands and the lightly cratered northern plains, indicating an age intermediate between these two extremes (7, 8). Crater size-frequency distribution curves of these regions have shapes similar to curves seen in the heavily cratered highlands, but at lower crater densities (8). The ridged plains appear to be the last unit to record the signature of the heavy bombardment period and thus probably formed near the end of this period (Fig. 2). The dating of rock samples from a ridged plains region could provide information necessary to determine if the end of heavy bombardment was an approximately simulataneous event throughout the inner solar system. This information has

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implications not only for the martian absolute chronologies but also for constraining the origins of objects responsible for the cratering record during the period of heavy bombardment. Additionally, since these plains are generally believed to be of volcanic origin, samples will provide compositional information of an intermediate stage of martian volcanism.

The selection of a landing site for the Mars Sample Return Mission near a ridged plains-northern plains boundary would provide opportunities for sampling terrains dating from both the heavy bombardment and post heavy bombardment periods and help place constraints on when the end of the heavy bombardment period occurred. A site in northeastern Lunae Planum is suggested because of its proximity to younger northern plains units and to channel outwash, where samples of material from further upstream may be collected. Locations in Syrtis Major Planum and Sinai Planum, although not offering the geologic diversity of the Lunae Planum proposed site, would also permit collection of rock samples from plains-ridged plains boundaries.

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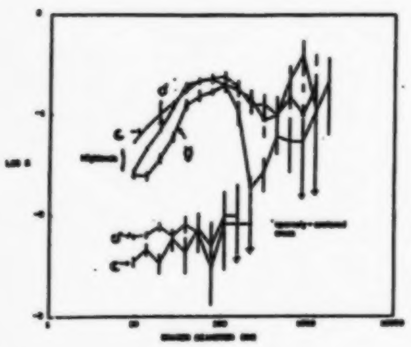

Fig. 1

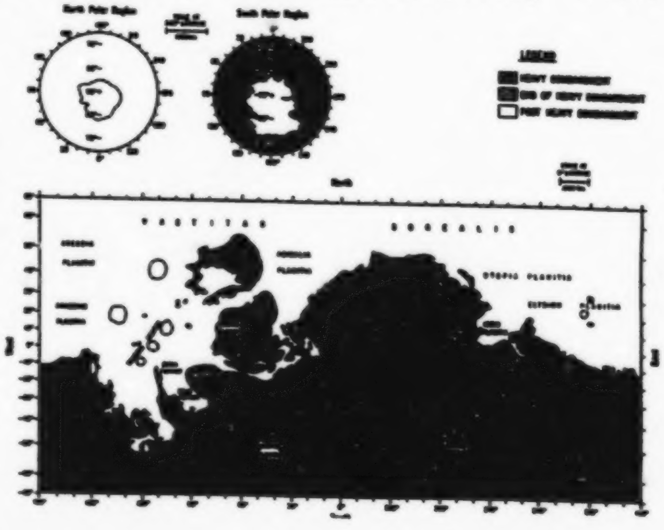

Fig. 2

N89-18295

PRIMARY SEDIMENTARY STRUCTURES AND THE INTERNAL ARCHITECTURE OF A MARTIAN SAND BODY IN SEARCH OF EVIDENCE FOR SAND TRANSPORT AND DEPOSITION.

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Our lunar experiences show that unmanned sample return missions, despite limitations on sample size, can produce invaluable data to infer crustal processes, regolith processes, regolith-atmosphere/ionosphere interaction processes, etc. Drill cores provide a record of regolith evolution as well as a more complete sample of the regolith than small scoops and/or rakes. We assume that a Mars sample return mission would include provisions for obtaining one drill core of at least one martian sand body. This is a good assumption because landing is likely to be on a sand dune [1] and coring is necessary for tracing past climatic imprints [2]. However, because the suspected processes of sediment production and sediment accumulation on Mars are unlike those on the Moon, but include some that are akin to terrestrial processes, it is necessary to devise new sampling strategies. Strategy should include experiments and sampling plans to acquire information on primary sedimentary structures and the architecture of sedimentary fills.

The expected scales of these structures are a few orders of magnitude smaller than the geomorphic features observed with earth and satellite based instruments. We submit that the pragmatic scale of sampling in the first few Mars sample return missions will be of limited value in answering large scale geomorphic questions. On the other hand, bed forms at mm and cm scales, and internal architecture of sand bodies at m scales, are amenable to sampling even on the first mission. Study of such bed forms are likely to provide information on the processes of transport and deposition. And, any interpretation of the origin of Martian sand would be vastly improved if petrologic and sedimentologic data are combined.

We propose that (a) a hole be drilled in a sand body to obtain continuous oriented cores; a depth of about 10m would be compatible with what we know of bed form hierarchy of terrestrial stream deposits, (b) two trenches, at right angles to each other and close to the drill-hole, be dug and the walls scraped lightly such that primary/internal sedimentary structures of the sand body become visible, (c) the walls of the trenches be made gravitationally stable by impregnation techniques, (d) acetate or other peels of a strip on each wall be taken, and (e) appropriately scaled photographs of the walls be taken at different sun-angles to ensure maximum ease of interpretation of sedimentary structures; and, to correlate these structural features with those in the core at different depth levels of the core.

Martian sand bodies to be sampled are likely to be of either fluvial and/or of aeolian origin. If fluvial, the sands are likely to have been transported in sinuous, or in anastomosing, or in braided channels, or, as debris flows. If the sand body chosen for sampling is indeed an alluvial fan deposit from a debris flow, it is likely to exhibit disorganized chaotic internal structures at the scale of sampling; only if the trenches are deep enough (≈10m) inverse grading etc. associated with such deposits may be deciphered. If the sand body represents, for example, a bar form in a braided channel then a sequence of internal structures may be seen both in the walls of the trenches, as well as in the corresponding drill core [3]; investigating a ≈10m section seems reasonable. If the sand body is of aeolian origin, perhaps a dune or an interdune deposit in a drying up environment, various internal structures would show up in the walls of the trenches depending upon the location of the trenches with respect to dune geometry [4]. However, if wind ripples and associated translational bed forms are preserved on Mars, then these small scale (a few mm to cm) structures should be visible in the drill core with coarser grains at the crest of these ripples [5,6]. This feature contrasts with sand ripples formed under water; there are other criteria as well to distinguish fluvial deposits from aeolian deposits [7]. A combination of trench photographs, detailed structural analysis of acetate peels, and the petrology of corresponding drill core samples would be helpful in interpreting all small scale primary sedimentary structures.

A case has been made that the Martian regolith may have significant amounts of $CaCO_3$ [8,9]. This carbonate may occur in several modes like calcrete layers, cement in the sand, and even as argillaceous limestone; any bedding may then be diagenetically enhanced [10]. Coring and trenching of the Martian regolith would be essential for an adequate investigation of processes leading to carbonate precipitation.

Orthogonal x-radiography and/or x-ray tomography via "catscan" methods of the drill core to visualize sedimentary structures and to correlate them with those seen in the trench walls, followed by textural analysis of drill core samples should provide data for interpreting the sedimentology of the sand body sampled.

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N89-18296

HOW WELL DO WE KNOW THE MARTIAN ABUNDANCES OF HIGHLY VOLATILE ELEMENTS ?

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Some popular models of planetary formation predict that among the terrestrial planets, Mars should contain the highest concentrations of the highly volatile, or atmophile elements. All Martian volatile abundance data are not consistent with these models, however. If SNC meteorite data are representative of Mars as a planet, they suggest that readily volatilized elements such as K, Pb, halogens, etc. are enriched on Mars over Earth by approximately a factor of two (1,2). Geomorphology of the Martian surface suggests abundant liquid water in the ancient past. On the other hand, the concentrations of noble gases, nitrogen, and carbon (as CO_2) in the Martian atmosphere per unit mass of the planet are orders of magnitude less than those of other solar system objects, including the total Earth and chondrite parent bodies (Fig. 1), which bracket Mars in heliocentric distance. The fact that the $^{40}Ar/^{36}Ar$ isotopic ratio on Mars is an order-of-magnitude larger than that of Earth indicates that at least part of the lower noble gas concentration of Mars is due to a smaller, original endowment of noble gases, and not just due to a lesser degree of planetary degassing into its atmosphere. But what about N, C, and H_2O? It has been suggested that large quantities of carbonates and water-ices or hydrated minerals exist in the upper Martian crust as a result of the present cold temperatures and extensive weathering of rocks over geological time (e.g. 3). It has been proposed that the unusually large $^{15}N/^{14}N$ isotopic ratio on Mars was caused by fractionation during massive atmospheric loss of atomic N over geologic history from an initial N abundance 10 to 20 times greater than that presently (4). These models suggest that Mars contains (or once contained) significant inventories of C, N, and H_2O.

All reservoirs of the highly volatile elements presumably were derived from the solar composition by various processes, which may have fractionated elements according to mass, ionization potential, adsorption properties, or other factors. Among the Earth, Mars's atmosphere, and carbonaceous and ordinary chondrites, the Ne/Ar and Kr/Ar elemental ratios each differ by less than a factor of three, but differ from solar values by a factor of $\sim$100. Likewise, the C/N and H_2O/N ratios are each similar for the Earth and C1 chondrites. In contrast, Fig. 2 shows that the C/Ar and N/Ar ratios vary by a factor of $\sim 10^6$ between the sun and carbonaceous meteorites, with Mars, Earth, and other objects showing intermediate ratios which lie approximately along a linear correlation. Three values of N/Ar shown for Mars correspond to the measured atmospheric ratio (left datum), and the lower and upper ratios (middle and right data) for the original volatile inventory with the assumption that massive N loss occurred to produce today's $^{15}N/^{14}N$. Unless the volatile component in Mars underwent a fundamentally different element fractionation process than those components in Venus, Earth, and chondrites, or unless the Martian degassing of N and ^{36}Ar were somehow decoupled (both unlikely), early Mars should lie near the trend defined by Fig.2. If Mars has lost significant amounts of atmospheric N, Fig.2 suggests that it contains a $C/^{36}Ar$ ratio between those of the Earth and C1 chondrites. Because the Earth and C1 chondrites have nearly identical H_2O/C ratios of $\sim$4, the Martian H_2O/C ratio is also expected to lie between those of the Earth and C1 chondrites.

The table below summarizes four models based on the above observations and gives some reasonable inferences of each for Martian volatiles. The table columns give 1) the volatile assumptions of the model, 2) the inferred Martian volatile concentrations relative to Earth, 3) the $N/^{36}Ar$ and $C/^{36}Ar$ ratios, 4) the percentage of Martian degassing inferred by the model, and 5&6) the equivalent global column heights of liquid water and solid $CaCO_3$ over the entire surface of Mars that would be formed from the model quantities of degassed volatiles. The Sub-Earth model (#1) is extreme and can probably be excluded because of the very low quantities of degassed H_2O it predicts and because it leaves no explanation for the high $^{15}N/^{14}N$. Models 2 and 3 predict a Mars that has considerably lower concentrations of atmophile elements than the Earth (e.g. Fig.1). These two models differ in their $C/^{36}Ar$ and $N/^{36}Ar$ ratios, and by a factor of 20 in concentrations of N,C, &H_2O. The amount of liquid water predicted on the surface of Mars by models 2 and 3 (11 and 50 meters) might be marginally large enough to produce the observed geomorphological features ascribed to water, but requires 100% planetary degassing. The SNC model (#4) has several advantages: 1) It is consistent with those planetary formation models that predict Mars to be a more volatile-rich planet than the Earth (at least in N,C,H_2O,K, etc., if not noble gases); 2) only a small fraction of the Martian volatiles have degassed into its atmosphere, consistent with the lower tectonic and volcanic activity of Mars compared to Earth; 3) the 50 meters of degassed liquid water is probably enough to produced observed features, yet small enough to be incorporated into crustal rocks; the 5 m of $CaCO_3$ could be mixed to relatively low concentrations into a deep regolith; 4) the fractional degassing of radiogenic ^{40}Ar (3%) is not larger than the fractional degassing of inherited gases (4%); 5) no special degassing of noble gases from pre-Mars planetesimals is required to explain the low abundances of noble gases in the present Martian atmosphere; this low abundance is explained as due to a difference in the ratio of noble gases to N,C,H_2O, i.e., more like C1 meteorites than like the Earth. Models #3 and #4 are based on the highest observed solar system ratios of $H_2O/^{36}Ar$ and $C/^{36}Ar$, yet each predict that no more than about 50 meters of liquid water ever existed at the surface of Mars. Model #4 predicts that Mars is enriched over Earth in volatile elements (except noble gases), whereas the other models require that Mars is depleted in all atmophile elements. If C,N, and H_2O were fractionated from noble gases during accretion of Mars, then a hybrid of models 3 and 4 is permitted. Unless H_2O was further fractionated from N, however, the layer of degassed liquid water at the surface would still be limited to about 50m.

These models predict a range of possible volatile contents and elemental ratios for Mars, and good estimates of the C,N, and H_2O contents of the Martian crust and regolith may be necessary to choose among them. These considerations emphasize the importance of collecting 1) subsurface samples which may contain these volatiles in weathered silicates, 2) shock-lithified regolith breccias near old craters which may preserve early volatiles characteristic of either the atmosphere or the regolith, and 3) young volcanic rocks which may indicate the concentrations of C, N, and K in the Martian interior. Recent studies (5) suggest that impact into porous material may have been an efficient mechanism of implanting ancient Martian gases into regolith breccias, and such breccias might contain evidence of compositional differences in past atmospheres.

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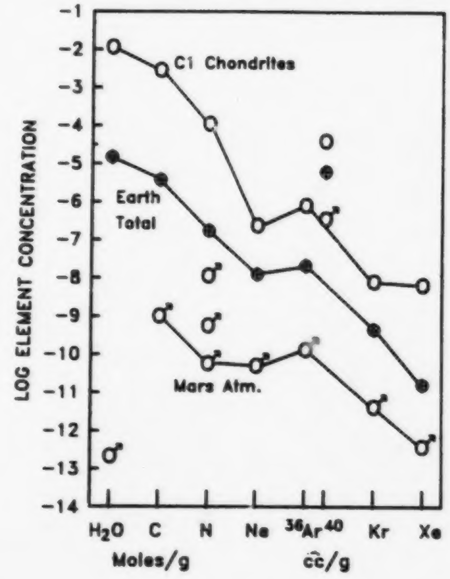
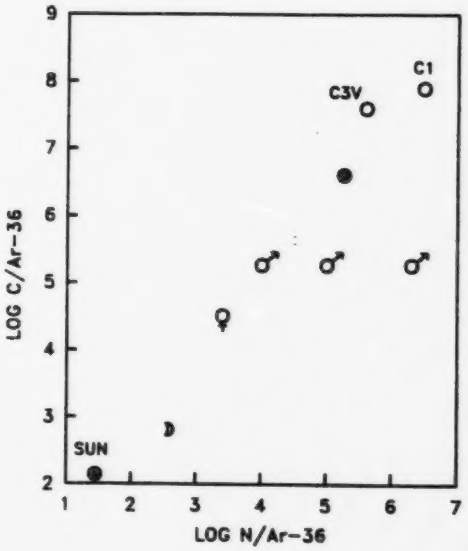
MODEL ASSUMPTIONS FOR MARS VOLATILES	VOLATILE CONC.	N,C/^{36}Ar RATIOS	DEGASSING ASSUMED	PLANET-TOTAL	
				H_2O	$CaCO_3$
1. Sub-Earth Obs.[N] "Real"; ($^{15}N/^{14}N$ Not Due to N Loss)	<< Earth	< Earth	100%	0.6m	0.05m
2. Volatile-Poor, Earth-Like [N]= 1.8X Lower Calc.	<< Earth	= Earth	100%	11m	1m
3. Intermediate [N]= Higher Calc.	< Earth	=C1 Chon	100% (^{40}Ar=6%)	50m	5m
4. SNC-Like	[N,C,H_2O,K] =2X Earth [^{36}Ar] =17% of Earth	=C1 Chon	4% (^{40}Ar=3%)	1250m (50m)*	125m (5m)*

(The two water & $CaCO_3$ values for Model #4 give total planet & surface inventory (in parenthesis)).

Figure 1 (below left). Concentrations (per gram of object) of several volatile elements or isotopes for the Martian atmosphere, C1 carbonaceous chondrites, and the total Earth inventory. Figure 2 (below right). Log plot of the element ratios $C/^{36}Ar$ and $N/^{36}Ar$ for the Sun, lunar regolith, Venus, Earth, Mars, C1 carbonaceous chondrites, and C3V chondrites. The three values for Mars represent (from left to right) the observed atmosphere and the lower and upper limits to the initial planetary inventory, calculated assuming that massive nitrogen loss caused the observed increase in $^{15}N/^{14}N$ (4).





N89-18297

A MARINERIS VALLIS SAMPLE SITE.

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Consideration is given to the choice of a Marineris Vallis canyon site in that it may offer the widest possible variety of martian units with a minimum amount of "roving". We support this in the classical comparison of Marineris Vallis with the Grand Canyon of the U.S.A. It is well-known to american geologists that most of the geological units in the U.S. may be found here in one section. Might not the martian canyon offer a similar selection but only more so in view of its much greater size?

Another advantage lies in it being possible to sample the whole section from bottom to top; from one sole landing site. The idea proposed here is to effect a kind of stratigraphic well along the canyon wall with the object of being able to study the entire stratigraphic column here exposed. In this way we should be able to deduce the kind of climates and erosional cycles in mars'past. Not only that, but be able to decide what orogenic cycles cycles have taken place during martian history and how they have affected the planetary surface. Granulometric studies will also show us the kinds of erosion that have prevailed in the past and the natureof the source areas.

The exact location of the site is of prime importance in order to try and have the oldest possible martian unit available. Initially we had considered a deep, narrow portion on the canyon's main West to East stretch. This however maybe complicated by the nature of the huge domal structure underlying the canyon's headwaters whose radiating lineaments are reminiscent of an Earthly volcanic edifice. If this last should be the case then a site along one of the South to North channels in the East is considered.

The canyon bottom can yield the most recently deposited sediments laid down on its floor while the wall immeadiately adjacent to it should yield the oldest unit, be it igneous or metamorphic as is the Vishnu schist on Earth. Obviously as the gouge sample is taken up the canyon wall we should get progressively younger.

A system whereby this sampling may be effecting is proposed based on a combination of a skip with a wire-line core-barrel method. The final design will depend more on the completeness of the core to be taken as the entire section is that long that the weight of the core of the whole section may well be prohibitive for return to Earth unless several returns are envisaged. As can be seen the wire-line system is operated from a static head-gear in much the same way as an oil well implying a lander not needing mobility of any kind-a destinct advantage.

N89-18298

FLUID INCLUSIONS IN MARTIAN SAMPLES: CLUES TO EARLY CRUSTAL DEVELOPMENT AND THE HYDROSPHERE;

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Fluid inclusions (FI's) in natural materials have provided unique and crucial evidence for understanding many terrestrial geologic processes (see {1} for extensive overview). They are unique because they provide the only direct sample of any fluid phase (silicate melt, supercritical fluid, liquid, gas) present during some portion of the history of the sample. FI's have a wide range of sizes ($<1\mu$ to $>100\mu$) but most commonly are <30-50μ in size and must be >2-5μ to be studied with a light microscope. They are preserved as imperfections within mineral grains, may be equant to highly irregular in shape, may contain 0-3+ separate fluid phases at room temperature, 0-5+ solid species (0 or 1 most common), and were trapped either during original growth of the mineral or during the healing of microcracks later in the mineral's or rock's development. A wide range of microanalytical techniques are available to characterize both compositional and pressure-volume-temperature (P-V-T) properties of the inclusion contents. Such laboratory analysis permits extrapolation back to the conditions at the time of trapping and often provides the crucial bit(s) of evidence to resolve larger questions.

Major questions about Mars that could be illuminated by examining fluid inclusions in Martian samples include (1) the nature, extent and timing of development (and decline) of the hydrosphere that existed on the planet, and (2) the evolution of the crust. Fluid inclusion analyses of appropriate samples (see below) could provide critical data to use in comparison with data derived from analogous terrestrial studies.

Solid rock samples returned from Mars could well contain a variety of inclusions that record information both from the time of the rocks formation as well as later events that have occurred to and around the sample. Magmatic rocks, either intrusive or extrusive, will contain now largely solid inclusions that represent the bulk(?) magma composition at various times in the crystallization of the sample. In basaltic compositions (low angle flank slopes; Olympus Mons?, Alba Patera?) olivine is the most propitious host mineral for magmatic inclusions; in more silicic compositions (steeper slopes; Elysium Mons?), quartz, if present, provides the best host for liquid/gas inclusions. In addition to melt inclusions, these same samples (especially the more silicic ones) are likely to contain trapped, largely fluid, inclusions that preserve the volatile phase present during the crystallization or cooling process. This volatile phase may have evolved directly from the magma during cooling, may be "groundwater" present at the site of magmatic activity and moved in response to thermal convection, or a combination of the two. [Lunar samples contain solid melt inclusions but no liquid inclusions, presumably reflecting the anhydrous nature of the melts and the lack of a hydrosphere during lunar development.] The presence of polar water- and carbon dioxide-containing "icecaps" on Mars as well as the abundant evidence for widespread liquid water early in the geologic history of Mars strongly suggest that appropriate samples will contain fluid inclusions. Radiometric age dating of the same samples would address the absolute timing of major (or minor) hydrothermal activity and could be extended to deal with the timing of surficial (or near surface) hydrologic processes.

The development and maturation of the Martian crust would, in light of evidence for a hydrosphere, result in thermally driven convection cells of dominantly aqueous fluids adjacent to shallow intrusive igneous bodies. Terrestrial analogs would include the Skaergaard Intrusion in Greenland {2} and many porphyry-hosted copper deposits of the southwest U.S. {3}. Convecting aqueous fluids leave definite light stable isotopic and geochemical signatures as well as abundant fluid inclusions. Intrusive igneous rocks may be exposed at the surface by major tectonic processes coupled with erosion, by large impact excavations, or by more local uplift and exposure (such as caldera formation).

Sample requirements for a Martian return mission are not too stringent for this proposed study. Any solid rock that can be thin sectioned provides a potential host material (whether it has usable inclusions is another matter). Fluid inclusions are commonly studied in doubly polished (top and bottom) chips or plates that may be thin section thickness (30μ) or up to 0.5mm or more depending on the grain size and clarity of the minerals. Rocks from anywhere on Mars would be welcome but the best samples would come from rifts (Valles Marineris) and fractures on the flanks of, or from the caldera rims of, the large volcanic edifices (i.e. Olympus Mons, Tharsis Ridge, Elysium Planitia bulge). Another interesting area would be near the polar regions where the regolith and upper crust are likely saturated with a (frozen) fluid phase. Nearby igneous activity could melt the trapped fluid and allow it to be preserved as fluid inclusions.

For this study, sample handling and return restrictions are unlikely to be as restrictive as the needs of other investigators. The main constraint is that the samples not be subjected to excessively high temperatures. An aqueous fluid inclusion trapped at elevated pressure and temperature will commonly consist of liquid "water" and water vapor at room temperature. Heating (such as is done in the laboratory to fix P-V-T data for the inclusion) results in moderate pressure increases up to the liquid-vapor homogenization temperature followed by a sharp increase in pressure with continued heating because the inclusion is effectively a fixed volume system. This increased pressure can rupture the inclusion; precise limits are dependent on size, shape, and composition as well as the host material. Qualitatively, the behaviors of other common phases are the same but different species and mixtures (i.e. CO_2) will have their own pressure response to increased temperature. Therefore as long as the collected samples do not undergo more extreme P-T conditions than they have been subjected to on the Martian surface, the information that they presently contain will make it back to the laboratory.

In summary, appropriate samples returned from the Martian surface will likely contain fluid inclusions that will yield compositional as well as P-V-T data for a range of igneous and hydrothermal processes. In concert with other studies, these trapped fluids provide a unique and potentially critical piece of the puzzle of understanding Martian crustal evolution.

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N89 - 18299

SAMPLING THE OXIDATIVE WEATHERING PRODUCTS AND THE POTENTIALLY ACIDIC PERMAFROST ON MARS

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Summary. Large areas of Mars' surface are covered by oxidative weathering products containing ferric and sulfate ions having analogies to terrestrial gossans derived from sulfide mineralization associated with iron-rich basalts. Chemical weathering of such massive and disseminated pyrrhotite-pentlandite assemblages and host basaltic rocks in the martian environment could have produced metastable gossaniferous phases ("limonite" containing poorly crystalline hydrated ferric sulfates and oxyhydroxides, clay silicates and opal). Underlying groundwater, now permafrost on Mars, may still be acidic due to incomplete buffering reactions by wall-rock alteration of unfractured host rock. Such acidic solutions stabilize temperature-sensitive complex ions and sols which flocculate to colloidal precipitates at elevated temperatures. Sampling procedures of martian regolith will need to be designed bearing in mind that the frozen permafrost may be corrosive and be stabilizing unique complex ions and sols of Fe, Al, Mg, Ni and other minor elements.

Background. The high concentrations of Fe and S analysed by the Viking XRF spectrometers, together with optical properties, remote-sensed spectra, magnetic measurements, biological experiments, and thermodynamic calculations, indicate that oxidized Fe^{3+}- and SO_4^{2-}-bearing phases exist on the surface of Mars [1,2]. Because constituent minerals on Mars have not yet been identified directly, considerable speculation exists about the nature and origin of parent igneous rocks, their mantle sources, and weathering processes that have generated materials in the martian regolith. Many ambiguities could be alleviated if pristine samples now stable on Mars could be retrieved without being degraded under ambient conditions on Earth.

The mantle of Mars is believed to be more iron-rich than the Earth's mantle and to contain sulfur concentrations approximating chondritic compositions. Partial melting of this martian mantle would produce iron-rich basaltic magma which could be olivine-rich and/or pyroxene-rich and resemble terrestrial Precambrian komatiites. The normative mineralogy of such mafic or ultramafic rocks indicates the presence of Fe-rich olivines and pyroxenes plus accessory Fe-Ni sulfides, correlating with mineralogical and analytical data for SNC meteorites believed to have originated from Mars. Such iron-rich silicate and sulfide phases on Earth are highly vulnerable to oxidative chemical weathering reactions, during which metastable phases and transcient chemical species in aqueous solution are formed.. They may still exist near the surface of Mars. Research on oxidized cappings or gossans [3,4] overlying sulfur-bearing mafic and ultramafic igneous rocks provide guidelines for sampling and storing pristine materials from the weathered surface of Mars.

Chemical Weathering Reactions. Near-surface oxidation reactions [4,5] of pyrrhotite-pentlandite (+/- pyrite, chalcopyrite) assemblages associated with terrestrial komatiites are catalysed by pyrite which may be present either as a primary phase or be formed during deep-weathering reactions (e.g. $Fe_7S_8 + 6Fe^{3+} = 4FeS_2 + 9Fe^{2+}$). Pyrite in contact with aerated groundwater generates strongly acidic (pH 2 to 5) and sulfate-rich ($\sim 10^{-2}$m) solutions (e.g. $2FeS_2 + 2H_2O + 7O_2 = 2Fe^{2+} + 4SO_4^{2-} + 4H^+$) which stabilize and mobilize simple and complex ions of Fe, Al, Mg, Ni, etc. Above the water table further oxidation occurs to insoluble Fe(III) oxides (e.g. ferrihydrite: $4Fe^{2+} + 6H_2O + O_2 = 4FeOOH + 8H^+$) and sulfates (e.g. jarosite: $6Fe^{2+} + 4SO_4^{2-} + 9H_2O + 3/2\ O_2 + 2(K,Na)^+ = 2(K,Na)Fe_3(SO_4)_2(OH)_6 + 6H^+$). Acidic groundwater produced by the oxidation of sulfides promotes chemical weathering reactions of feldspars and ferromagnesian silicates to clay silicates and Fe(III) oxides in host igneous rocks. On Earth, the pH of such aqueous solutions, now predominantly oceans, is raised when seawater permeates through highly fractured basalts erupting along spreading centers. Similar acid-buffering reactions by wall-rock alteration may be incomplete on Mars because plate tectonic activity appears to have been minimal there. The fields of relative stabilities of simple Fe^{2+} and Fe^{3+} ions and some of the more common Fe(III) minerals found in gossans are depicted on Figure 1. This pE-pH diagram shows that dissolved Fe^{2+} ions could be stabilized in less oxygenated groundwater if it were acidic on Mars. However, ferrous ions would be readily oxidized to Fe^{3+}-bearing phases when returned to Earth unless adequate precautions were taken to avoid conversion to ferric iron.

More rigorous analyses of ion speciation in aqueous sulfuric acid solutions [6-9] indicate that at low pH dissolved complex ions of Fe, Al, Mg, etc., exist, including $FeSO_4^0$, $FeSO_4^+$ and $Fe(SO_4)_2^-$, and that at elevated temperatures significant concentrations of $FeOH^+$, $FeOH^{2+}$ and $Fe(OH)_2^+$ appear. These complex ions faciliate the formation of sols containing $Fe_3(SO_4)_2(OH)_5.2H_2O$ (carphosiderite) and $Fe_4SO_4(OH)_{10}$ (glockterite) which are precursors to colloidal jarosite and other insoluble hyroxo ferric sulfate minerals [2,6]. Therefore, temperature must be controlled (in addition to pH and dissolved oxygen) during sample retrieval from Mars in order to stabilize prisine complex ions and sols that may be present in frozen permafrost there.

Measurements on Returned Martian Samples. After refrigerated drill-cores taken through a gossan - frozen permafrost horizon on Mars are returned to Earth, they would be amenable to a variety of techniques including: (1) x-ray diffraction using cold-finger stages, to identify mineral phases present; (2) spectrophotometric determinations of dissolved complex ions of Fe and Ni in frozen solutions; (3) transmission electron microscopy, to examine sols and colloids; (4) low temperature Mossbauer spectroscopy, to characterize Fe-bearing phases; (5) near infrared spectroscopy, to identify H_2O, OH^- and H_3O^+ species in solid phases and frozen solution; and (6) measurements of E_h and pH.

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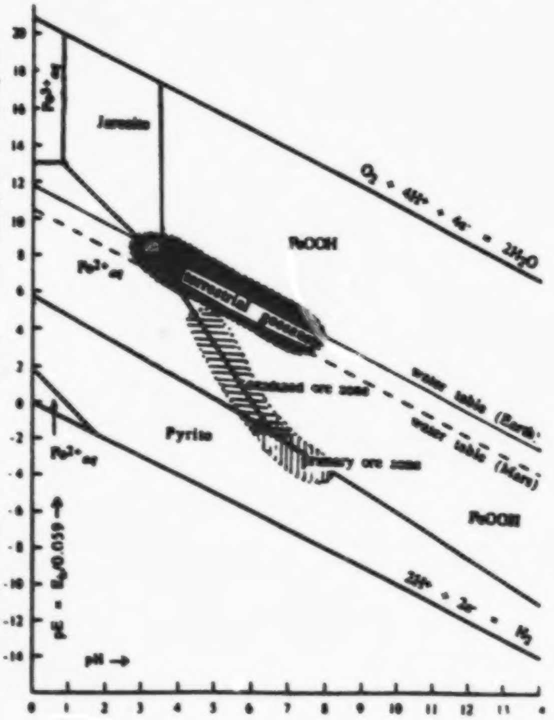

Figure 1. Eh-pH diagram for pyrite in equilibrium at 25° with dissolved Fe (10^{-4}m), S (10^{-2}m) and K (10^{-4}m) ions and the oxidative products jarosite $[KFe_3(SO_4)_2(OH)_6]$ and FeOOH [based on reference 10]. Ranges of pE and pH values associated with oxidized pyrrhotite-pentlandite ore assemblages are shown [see references 3-5]. Note that at 298.15°K, $E_h = 0.05916 \times pE$.

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N89-18300

SULFIDE MINERALIZATION: ITS ROLE IN CHEMICAL WEATHERING OF MARS

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Summary. Pyrrhotite-pentlandite assemblages in mafic and ultramafic igneous rocks may have contributed significantly to the chemical weathering reactions that produced degradation products in the martian regolith. By analogy with terrestrial processes, a model is proposed whereby supergene alteration of these primary Fe-Ni sulfides on Mars has generated secondary sulfides (e.g. pyrite) below the water table and produced acidic groundwater containing high concentrations of dissolved Fe, Ni and sulfate ions. The low pH solutions also initiated weathering reactions of igneous feldspars and ferromagnesian silicates to form clay silicate and ferric oxyhydroxide phases. Near-surface oxidation and hydrolysis of ferric sulfato- and hydroxo-complex ions and sols formed gossans above the water table consisting of poorly crystalline hydrated ferric sulfates (e.g jarosite), oxides (ferrihydrite, goethite) and silica (opal). Underlying groundwater, now permafrost, contains hydroxo sulfato complexes of Fe, Al, Mg, Ni, etc., which may be stabilized in frozen acidic solutions beneath the surface of Mars. Sublimation of permafrost may replenish colloidal ferric oxides, sulfates and phyllosilicates during dust storms on Mars.

Background. The presence of massive volcanoes in the Tharsis and Elysium regions, the distinctive petrology of SNC meteorites, and a compendium of results from the Viking Lander experiments all point to extrusive and plutonic mafic and ultramafic igneous rocks on Mars having analogies to terrestrial komatiites [1]. On Earth, the latter are associated with massive and disseminated sulfides containing pyrrhotite, pentlandite, and accessory pyrite and chalcopyrite [2]. Near-surface oxidation of these sulfides have produced conspicuous rust-colored gossans, which often betray the occurrence of unexposed ore deposits (Figure 1). Studies of gossans and sub-surface minerals [3-5] suggest pathways of oxidative weathering reactions that may be applicable to Mars.

Pyrite is pivotal to chemical weathering reactions of sulfides. It may occur as a minor constituent of primary igneous sulfides, or be formed by supergene reactions involving deep weathering of pyrrhotite (see equation {1} in Table 1.). At or near the water table, oxidation of pyrite by aerated groundwater occurs {6},{7}. Ferric iron liberated in this reaction, not only promotes the initial alteration of pyrrhotite {1} and of pentlandite {2} to secondary sulfides in the absence of dissolved oxygen, but also aids the dissolution of pyrite {5} below the water table. Supergene enrichment reactions also occur there {3},{4}, leading to high concentrations of Ni, etc. in secondary sulfides. Strongly acidic and sulfate-rich groundwater is produced which stabilizes dissolved ferrous iron and a variety of complex ferric ions [6] including those listed in {8} and {9}. At elevated temperatures, these complexes produce of a variety of hydroxo-ferric sulfate sols [7] (e.g carphosiderite {8},{9}), which may be the precursors to a number of ferric sulfate minerals [8] often found in gossans in arid regions. In less acidic environments above the water table, dissolved ferric ions and monodispersed sols are hydrolysed to poorly crystalline FeOOH phases (e.g. ferrihydrite, goethite {10},{11},{12}), which coexist with silica (opal, jasper) and the hydrated ferric sulfate minerals in gossans. The fields of relative stabilities of gossaniferous phases are depicted in the oxidation-acidity diagram shown in Figure 2.

Reactions {4} to {11} formulated in Table 1 demonstrate that groundwater in the vicinity of oxidizing sulfides is highly acidic. Such low pH solutions promote the chemical weathering of feldpars, pyroxenes and olivine in host igneous rocks [9], liberating dissolved silica, Al, Ca, Mg, Na and additional Fe ions, and producing secondary clay silicates (e.g. smectite) and iron oxyhydroxides. On Earth, seafloor basalts and gabbros erupting along submarine spreading centers have undergone extensive hydrothermal alteration by seawater circulating through underlying tectonically-fractured oceanic crust. As a result, the acidity of aqueous solutions is buffered by seawater-basalt interactions, leading to the slight alkalinity (pH 8.2) of present-day terrestrial oceans.

SULFIDE WEATHERING ON MARS

Burns, Roger G.

The oxidative power of atmospheric oxygen is the driving force in the weathering of sulfides (in the absence of bacterial activity). The dissolution of oxygen in groundwater and its migration to sulfide reaction centers involve diffusion processes and are probably rate-controlling. When the concentration of dissolved oxygen is very low and the supply of water is limited, oxidative reactions become sluggish and involve hydrogen peroxide. Furthermore, ferric-bearing solutions may liberate elemental sulfur {13},{14},{15}. Thus, metastable sulfur is observed in pyrite-jarosite-sulfur assemblages associated with some ultramafic pyrrhotite-pentlandite deposits [10].

Martian Weathering. On Mars, where plate tectonic activity appears to have been insignificant, vast volumes of iron-rich basaltic magma has reached the surface of the planet via immense shield volcanoes. Fracturing associated with this volcanism, as well as impact cratering, facilitated deep-weathering reactions by permeating groundwater early in the history of Mars. However, the apparent absence of spreading centers and subduction zones, which cause recycling of the Earth's crust, has minimized acid-buffering of aqueous solutions by wall-rock alteration on Mars. Therefore, the acidity of groundwater, now permafrost, may have been maintained during the chemical evolution of the martian surface, thereby aiding the solubility and transport of Fe, Al, Mg, Ni, silica, etc. Geomorphological evidence attesting to the flow of water on Mars suggests that gossan-forming reactions may have occurred in the past. However, the present-day cold surface of Mars has impeded deep-weathering of sulfides in host basaltic rocks due to slow reaction rates and restricted access of dissolved oxygen or ferric iron to reaction centers. Nevertheless, some oxidative weathering may still be occuring in the frozen environment on Mars, as indicated by the oxidation of Fe and FeS phases observed in Antarctic meteorites [11]. When sublimation of martian permafrost occurs, species held in solution could be hydrolysed, precipitated as colloidal materialland transported in dust storms..

Discussion. Evidence for gossan formation on Mars stems from several sources. First, remote-sensed reflectance spectral profiles are matched closely by ferrihydrite-silica gels and jarosite-bearing clay assemblages [12]. Second, jarosite which is so characteristically an oxidative weathering product of iron sulfides, may be present in SNC meteorites [13,14] believed to have originated from Mars. Third, the magnetic phase detected in the Viking magnetic experiment [15] may be remnant pyrrhotite which has been incompletely oxidized, particularly if the level of the water table has dropped on Mars. Finally, a limited supply of water and a low concentration of dissolved water, which favor the formation of hydrogen peroxide and promote the production of peroxide and superoxide phases, may account for results obtained in the Viking biology experiments [16].

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Table 1. CHEMICAL WEATHERING REACTIONS INVOLVING SULFIDES

{1} Fe_7S_8 (pyrrhotite) + $6Fe^{3+} = 4FeS_2$ (pyrite) + $9Fe^{2+}$
{2} $(Fe,Ni)_9S_8$ (pentlandite) + $2Fe^{3+} \Rightarrow 3Fe^{2+} + (Fe,Ni)Ni_2S_4$ (violarite)
{3} $(Fe,Ni)Ni_2S_4$ (violarite) + $Ni^{2+} \Rightarrow Fe^{2+} + (Ni,Fe)Ni_2S_4$ (polydymite)
{4} Ni_3S_4 (polydymite) + $H_2O + 15/2\,O_2 = 3Ni^{2+} + 4SO_4^{2-} + 2H^+$
{5} $FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+$
{6} $2FeS_2 + 2H_2O + 7\,O_2 = 2Fe^{2+} + 4SO_4^{2-} + 4H^+$
{7} $4FeS_2 + 2H_2O + 15\,O_2 = 4Fe^{3+} + 8SO_4^{2-} + 4H^+$
{8} $2FeSO_4^+ + FeOH^{2+} + 6H_2O = Fe_3(SO_4)_2(OH)_5.2H_2O$ (carphosiderite) + $4H^+$
{9} $Fe(SO_4)_2^- + 2FeOH^+ + 4H_2O = Fe_3(SO_4)_2(OH)_5.2H_2O + H^+$
{10} $Fe^{3+} + 2H_2O = FeOOH$ (ferrihydrite, goethite) + $3H^+$
{11} $FeSO_4^+ + 2H_2O = FeOOH + SO_4^{2-} + 3H^+$
{12} $Fe_3(SO_4)_2(OH)_5.2H_2O = 3FeOOH + 2SO_4^{2-} + 4H^+ + H_2O$
{13} $FeS_2 + 2Fe^{3+} = 3Fe^{2+} + 2S$
{14} $Fe_7S_8 + 14Fe^{3+} = 21Fe^{2+} + 8S$
{15} $(Fe,Ni)_9S_8 + xFe^{3+} \Rightarrow yFe^{2+} + zNi^{2+} + 8S$

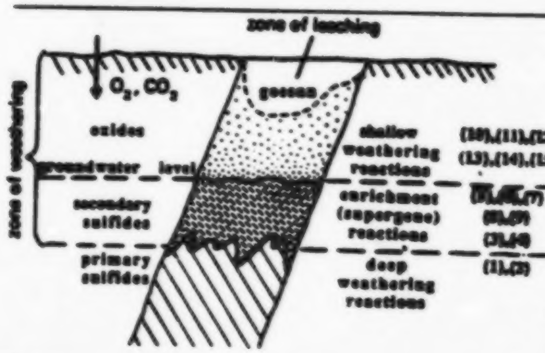
zone of leaching
O_2, CO_2
gossan
oxides
zone of weathering
groundwater level
secondary sulfides
primary sulfides
shallow weathering reactions
(10),(11),(12
(13),(14),(15
enrichment (supergene) reactions
(8),(9)
(3),(4)
deep weathering reactions
(1),(2)

Figure 1 (above). Zones of weathering associated with gossan formation above sulfide mineralization. The scale of the sulfide vein may be a few microns to several meters in diameter. Reactions {1} to {15} correspond to those in Table 1.

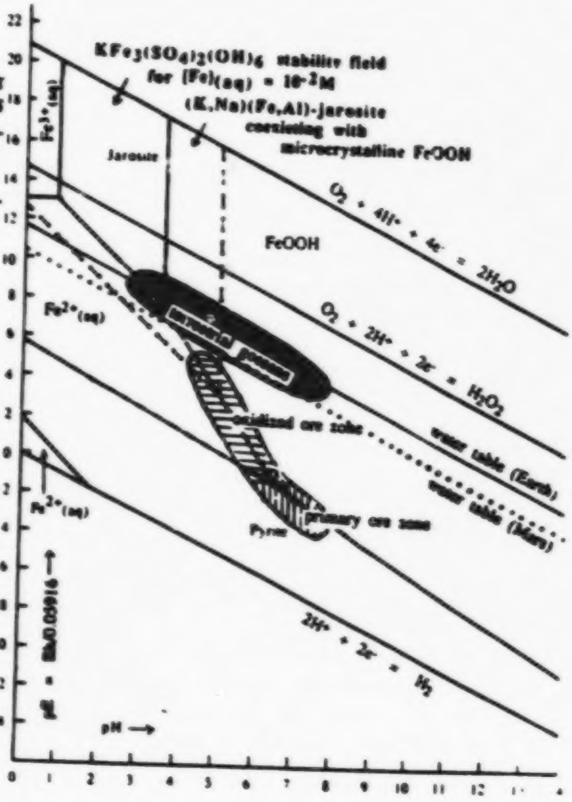

Figure 2 (right). Equilibrium diagram for pyrite and its oxidative products, including jarosite and FeOOH, occurring in gossans at 25°C (modified from [5]). Ranges of pE and pH measured in oxidized pyrrhotite-pentlandite assemblages are shown [3-4], as well as values for dissolved oxygen in groundwater on Earth and Mars. (At 298.16°K, Eh = 0.05916 x pE.)

N89-18301

SURFACE COMPOSITIONAL AND STRUCTURAL ASPECTS OF MARTIAN SAMPLES; D. A. Cadenhead, Department of Chemistry, State University of New York at Buffalo, Buffalo, NY 14214.

There are many excellent reasons to examine the surface composition of a wide range of Martian samples. The existing spectral data indicate that many dust and soil particles have a "thin" Fe^{+3} layer with a typical particle size in the 10 µm to 400 µm range. In view of the high CO_2 content of the atmosphere (1) one might expect that surface carbonates should be present. In addition to chemisorbed material there will probably exist physisorbed atmospheric components of the atmosphere including oxygen, nitrogen and water vapor. The latter could possibly give rise to some hydrated minerals.

Using ultra-high-vacuum/mass spectrographic techniques it should be possible to detect physisorbed and moderately strong chemisorbed species on the particle surfaces with a temperature programmed degassing procedure (2). In some instances such an approach is capable of helping distinguish between volcanic and impact generated materials by detecting the presence of fumerolic gases (3). Such gases typically condense on the exterior of the ejected particles. Additionally surface atomic and chemical compositions should be examined by a combination of modern surface analytical techniques. The combination we currently have in Buffalo at SUNY would appear to be one of the best available including ESCA (150 µm spot capability) Auger (SAM) with 300A focussing for surface compositional surveys, SIMS for high sensitivity trace element detection and ISS for immediate surface layer analysis.

One of the major questions the Viking mission was supposed to answer was whether or not primitive life forms (microorganisms) existed on the Martian surface. The confusing results obtained (an initial burst of radioactive CO_2 formed during the release experiment, but no exponential increase and no organics formed) left this question essentially unanswered. One of the important conditions for a life form is probably the existence of liquid water. It has been claimed that there are extensive regions where the surface pressure exceeds that of the triple point of water. A detailed evaluation by C. B. Farmer (4) concludes that liquid water may exist in equilibrium or in an evaporative steady state, particularly when mixed or covered by a significant layers of fine dust particles. The best areas, Farmer suggests, would be a low elevation with a latitude on the poleward side of the subsolar point, at or about the summer solstice. The dust contribution to the existence of liquid water is thought to exist when slow evaporation rates through the inter-dust-particle-channels or pores pertain.

We would like to extend this concept by pointing out that capillary condensation can stabilize the existence of liquid water at relative pressures as low as 0.2. This phenomenon occurs in pores of 20-500A diameter or width (mesopores) and may be predicted by application of the Kelvin equation:

$$RT\ln p/p^{o} = \gamma V\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

where p/p^o is the relative pressure; γ,V the surface tension and molar volume of the water. R_1 and R_2 would define the curvature of the pore being positive when measured from the more dense solid or liquid phase. Mesopores such as these are known to exist in terrestrial volcanic samples being formed during the "plastic" cooling and degassing stage of the magma. They are rare in lunar samples (5) due to the lack of an atmosphere, but should exist in Martian volcanic cinders. In addition to elevation and latitude restrictions, volcanic sites should be considered for possible liquid water retention and possible life forms.

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N89-18302

OVERVIEW OF MARS: VIKING RESULTS.

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As a result of the Viking orbiter observations, the entire surface of Mars has been imaged at a resolution of 200 meters, and fractions of the surface down to resolutions of 10 meters, the thermal inertia of the entire surface is known to a resolution of 30 km, and the water content of the atmosphere has been monitored over two martian years. In addition, at two sites, the Viking landers analyzed the atmosphere, imaged the surface, performed organic and inorganic analyses on the soil, and monitored meteorological conditions for almost three martian years. The results show that Mars is a highly variegated planet with a long and complex history of volcanic and tectonic activity, a surface that has been modified by wind, water and ice, and an atmosphere that has experienced substantial changes, both periodic and secular. The variety of processes that have operated on the surface, and the long history of their action, result in a much broader range of sampling problems and opportunities than was experienced in the case of the Moon.

As on most other solid planetary bodies, impacts have played a major role in the evolution of the surface. Approximately two thirds of the surface is covered with heavily cratered terrain that has a crater size frequency distribution typical of surfaces that formed at the tail end of heavy bombardment (Strom, 1986). The cause of the planet-wide dichotomy is unknown, but Wilhelms and Squyres (1984) sugggest that it results in part from a very large and ancient impact. The impact scar has since been partly filled with a variety of sedimentary and volcanic deposits. The heavily cratered terrain, like the lunar highlands, is probably underlain by a kilometers deep megaregolith of fractured and brecciated rock. The terrain is almost everywhere dissected by small branching valley networks, most large flood features originate in the heavily cratered terrain, commonly in areas where the ground has seemingly collapsed to form chaotic terrain, and, at latitudes greater than 30°, the cratered terrain appears softened as though the near-surface materials had flowed, and extensive debris flows form at the base of escarpments (Squyres and Carr, 1986). These three characteristics (valley networks, source of floods, flow of surface materials) suggest that the heavily cratered terrain was, initially at least, water or ice rich. In the equatorial regions the surface may have lost much of its unbound water down to depths of a few hundreds of meters, as a result of diffusion into the atmosphere and freezing out at the poles (Fanale et al., 1986).

The ancient cratered terrain is in many places buried by younger deposits. Small patches of younger plains occur throughout the highlands between craters and on crater floors. These plains are only occasionally dissected by valley networks and many have ridges like those on the lunar maria. They are generally assumed to be volcanic but this is not proven. The bulk of the demonstrably volcanic rocks occur in the two main volcanic provinces, Tharsis and Elysium. Large lava flows are visible throughout Tharsis, on most of the large shields, and in parts of Elysium. The large size of the flows, their spectral characteristics, and their resemblance to lunar and Hawaiian flows suggest that they are basaltic in composition. Other extensive ridged plains, such as Lunae Planum, Chryse Planitia and Syrtis Major Planitia, may also formed of mafic lavas, but they are largely devoid of flows, or other demonstrably volcanic features. Pyroclastic deposits may be common. Various features in Elysium, Alba, Valles Marineris, and southern

Amazonis have been interpreted as ash deposits (Mouginis-Mark et al., 1984; Lucchitta, 1985; Scott and Tanaka, 1982; Squyres et al., 1987). Most workers view the pyroclastic activity as the result of interaction of lava with near-surface ice. Not all the sparsely cratered plains are volcanic. Amazonis Planitia, the peripheral regions of Elysium Planitia, the low lying northern plains, and parts of the floors of Hellas and Argyre, all lack volcanic features. Parts of the surface in these regions have either stratified or chaotic textures. The textures may indicate sediments deposited by the large floods which debouched into these areas.

The role of water in the evolution of the surface is of fundamental geologic and climatologic importance. The total inventory is currently being reassessed upward (Pepin, 1986; Carr, 1987). Shortly after the Viking mission, estimates from the noble gas content of the atmosphere and the nitrogen isotopes in the atmosphere suggested between 5 and 20 meters of water had outgassed. A similar low value was obtained by Dreibus and Wanke (1986) from studies of SNC meteorites. Such low values appear inconsistent with the large amounts of water erosion that has occured, and the abundant evidence for ice at the surface. From the measured amounts of erosion, Carr (1986) estimated that at least 500 meters of water has outgassed. This can be reconciled with the low geochemical estimates if the planet lost a substantial part of its early atmosphere by impact erosion or hydrodynamic escape. Recent measurements of a high D/H ratio (Owen, personal comm.) indicate that Mars has lost a substantial amount of hydrogen. Such losses could only be achieved if the atmosphere was at one time substantially thicker than at present. If 500 m of water did outgass, then 10-20 bars of CO_2 and 0.15-0.3 bars of nitrogen probably outgassed also, and have subsequently been fixed in the ground as carbonates and nitrates.

Dust covers much of the martian surface, and could substantially affect sampling strategy. Radar, thermal, and visual data suggest that in the equatorial regions, the dust is thickest in Tharsis, Arabia, and Elysium (Christensen, 1986). Despite the omnipresence of dust, the reastablishement of albedo markings after dust storms, regional differences in spectral reflectivity, moderate resolution color differences, and the view from the Viking landing sites, all suggest that both blocks and bedrock are available for sampling. The mineralogical compoisition of the dust is still uncertain. Iron rich montmorillonite is consistent with the Viking biology and inorganic analysis results, but Singer et al. (1985) claim that there is little spectral evidence for minerals such montmorillonite or kaolinite that have Al-OH bonds. They suggest that some poorly crystalline material such as palagonite is the major component of the dust.

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SOIL MECHANICS ON THE MOON, MARS, AND MULBERRY; W.D. Carrier, III, Bromwell & Carrier, Inc., Lakeland, Florida

From a soil mechanics point of view, the Moon is a relatively simple place. Without any water, organics, or clay minerals, the geotechnical properties of the lunar soil are confined to a fairly limited range. Furthermore, the major soil-forming agent is meteorite impact, which breaks the big particles into little particles; and simultaneously, cements the little particles back together again with molten glass. After about a hundred million years of exposure to meteorite impact, the distribution of particle sizes in the soil achieves a sort of steady state. The majority of the returned lunar soil samples have been found to be well-graded silty-sand to sandy-silt (SM in the Unified Soil Classification System). Each of the particle size distributions plots within a relatively narrow band, which appears to be uniform over the entire lunar surface. This further restricts the range of physical properties of the lunar surface.

The most important factor affecting the behavior of the lunar soil is its relative density; i.e., how tightly the individual particles are packed together. Relative density, D_R, is defined as:

$$D_R = \frac{\rho_{max}}{\rho} \times \frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}} \times 100\%,$$

where ρ is the density of the soil as-deposited; ρ_{min} is the minimum possible density (i.e., as loose as the soil can be placed); and ρ_{max} is the maximum possible density (i.e., as dense as it can be packed). If $\rho = \rho_{min}$, $D_R = 0\%$ (very loose) and if $\rho = \rho_{max}$, $D_R = 100\%$ (very dense). The meteorite impacts loosen and stir the surface, but just a few centimetres down, the shock waves shake and densify the soil. Right at the surface, the soil is loose, with a relative density of about 30%. Ten to twenty centimetres deep, the soil is dense to very dense, with a relative density of 80% to more than 90%. The density of the sub-soil is much greater than can be accounted for by the weight of the over-lying soil. The relative density is greater, in fact, than can be achieved on Earth with heavy construction equipment. Consequently, the geotechnical properties of the lunar soil are relatively uniform and very safe with respect to bearing capacity, settlement, and trafficability. This was one of the most important geotechnical findings from the Apollo program and was deduced from penetrometer tests performed *in situ* and from laboratory tests performed on returned lunar samples.

In contrast, martian soils should exhibit an extremely wide range of properties. We already know that there is a small amount of water in the soil, greater than in the martian atmosphere. Furthermore, the soil is suspected to be smectitic clay. That makes two out of the three factors that greatly affect the properties of terrestrial soils (we do not believe,

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yet, that there are significant organics in the martian soil). Acted upon by wind and sun, the martian soil could range from a light fluff to a hard brick. Furthermore, desiccation cracks could occur in the clay with a width of one to two metres and depth of 10 metres or more. These cracks could be covered with loose soil and could represent a hazard similar to crevasses in a glacier. On the positive side, there could be large quantities of water trapped in the pores of the clay with could be mined (but not pumped). There may even be a groundwater table.

It is essential that certain tests be performed as soon as a sample is taken on the martian surface. These include: moisture content, pH, and cation and anion concentrations. Each sample must be carefully sealed for earth-return, otherwise, chemical reactions could occur which could alter its properties. It is also very important that penetrometer measurements be made on a systematic basis. For example, Lunokhods I and II conducted more than one thousand penetrometer tests over a combined traverse of 47 kilometres on the Moon. These tests provide a simple, rapid method of evaluating the condition of the soil, and for discriminating among different soil types and deciding which samples to collect.

A terrestrial analogue for the martian soils occurs in the region around the small town of Mulberry in central Florida. This is the center of phosphate mining in the U.S. A by-product of the ore-beneficiation process is a very plastic, smectitic clay. The phosphate industry produces approximately 36 million dry tonnes of clay each year. The clay is deposited hydraulically as a dilute slurry into large holding ponds, in many cases, deeper than 20 m. More than 40,000 hectares of clay ponds presently exist and about 1500 new hectares are created annually.

When a clay pond is reclaimed, the groundwater table is lowered as much as 10 m below the clay surface. The clay volume shrinks about 40% and an extensive network of cracks forms over the surface. The physical properties of the clay undergo enormous changes as the clay dries out. Of course, the moisture content in a reclaimed clay pond is much greater than is presently found in martian soil. Nonetheless, the pond represents an early stage in the development of the martian surface. In order to understand the present condition of the martian surface, it is essential to study its early formation. To know Mars, you must come to Mulberry, and I invite my geology and soil physics colleagues to visit us there.

N89-18304

SAMPLING THE ANCIENT VOLATILE-RICH AREAS OF MARS. A. F. Chicarro, Department of Geology, National Museum of Natural Sciences, 28006 Madrid, Spain.

Viking images clearly show areas with a high density of fluidized craters that also display a significant number of wrinkle ridges. Fluidized crater ejecta morphology may indicate that the target material was rich in volatiles at the time of the impact. Therefore, these areas are of the utmost importance in deciphering both the martian tectonic evolution and the amount of subsurface water, at times when more favorable conditions for life to evolve did exist on Mars.

Distribution of Martian ridges: Although a large number of extensional features are associated with Tharsis (I) and Elysium (2) geologic activity, the planet-wide distribution of ridges (3) suggests that Mars' tectonic history is far more complex than the Tharsis-dominated scenario (4) indicates. Like on the Moon and Mercury, ridges on Mars were formed under compressive stresses (5), probably as a result of thrust-fault mechanisms (6), although surface expressions and direct causes vary (7). Martian ridges are most easily seen on smooth plains of volcanic origin (8), but the majority of the I6,000 mapped and classified compressive features are located in the old terrains, far beyond Tharsis influence (9). In addition to Tharsis tectonic control (I0, II), Martian ridge distribution and orientations have also been influenced by the stresses related to the formation of large impact basins (I2). Compressive tectonics on Mars not only affect the upper layers but the whole lithosphere, However, the presence of subsurface volatiles contributes to form a low viscosity material, where compressive stresses are best expressed as ridges. Therefore, sampling the geologic environment of Martian ridges would prove most useful in determining the planet's tectonic evolution.

Fluidized craters and volatile content: Fluidized craters seem to be good indicators of subsurface volatiles in the target material at the time of the impact (I3). Although the exact volatile phase, water or ice, is still debatable (I4), changes in ejecta morphology indicate a different subsurface volatile content, each geologic unit having a different volatile storage capacity. Also, altitude control of crater morphology reflects a decrease in plain material thickness (and thus, volatile content)(I5). Fluidized craters on smooth ridged plains are slightly younger than the ridges they overlap. These terrains are of Lower Hesperian age (about 3.5 billion years)(I6). A comparison of ridge (Fig. I) and fluidized crater distribution (Fig. 2) shows that all areas with a high density of fluidized craters display a large number of ridges. Thus, smooth ridge plains have had a high volatile content. Ridge length, such as in Coprates or Hesperia Planum, seems to be related to the duration of the low viscosity state (I7), which also controls the density of fluidized craters, since they were formed when the meteoritic flux was about constant. Therefore, major ridge formation episodes did not occur without a long period of low viscosity. Thus, compressive tectonics have induced ridge formation at times and in areas of low viscosity and high volatile content.

Sampling sites and strategy: The lower parts of Coprates, Lunae Planum, and Hesperia Planum, are believed to be good sampling sites for determining water content in Lower Hesperian terrains, at times when atmospheric conditions, climate, geologic activity, etc., were very different than today (e.g., I8). It is in these areas that the most favorable conditions for ancient life to have evolved could be found, and not in the present water-rich regions. As an example, it is proposed to sample both the regolith and the bedrock on a 50 Km. traverse (Fig. 3), starting away from a 30 Km. crater and going towards the crater rim , where the bedrock could be easily sampled. This itinerary would cross at least one major ridge and the fluidized ejecta. A drilling device on the rover vehicle for subsurface sampling of the fluidized ejecta and ridge vicinity should be present. Both regolith and rock samples should provide new clues in determining Mars' geologic history. Sampling of any of the proposed landing sites on a sample return mission to Mars would allow several major scientific questions to be addressed: tectonic evolution, ancient water content, and the possibility of ancient life.

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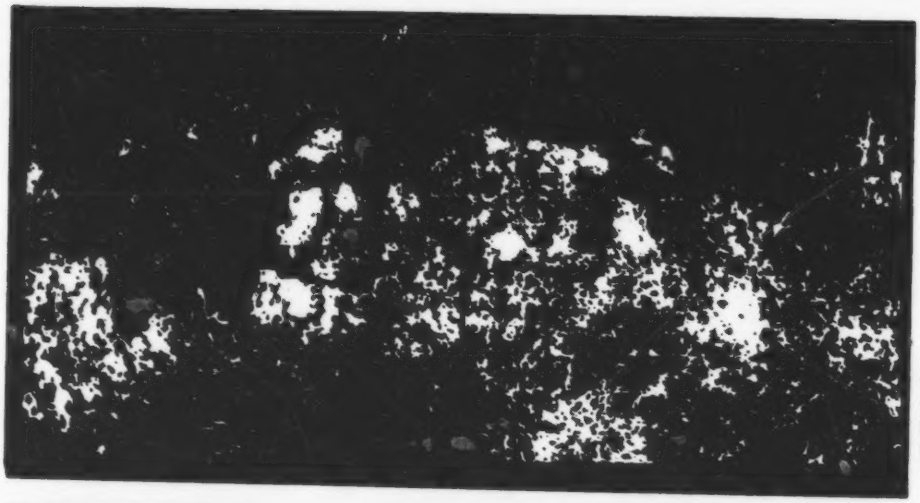

Figure I.

Computer-based map of all ridges on Mars, between latitudes of ±65°.

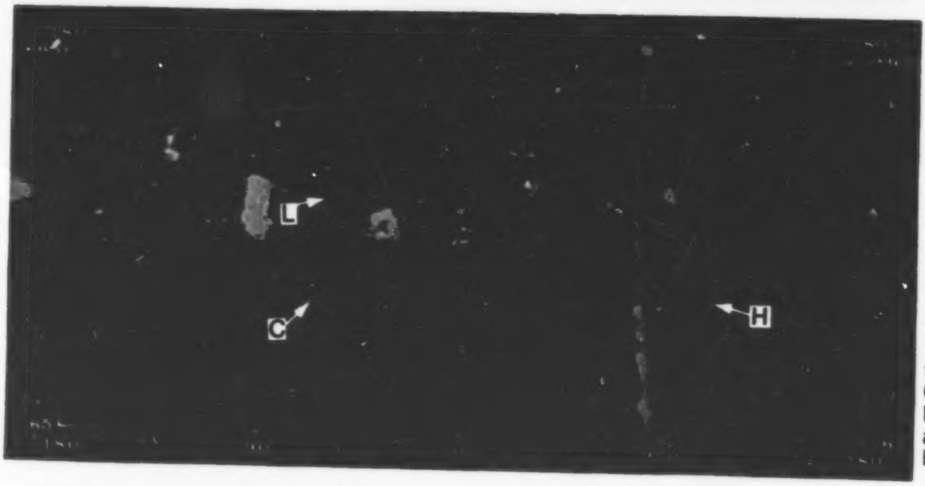

Figure 2.

Map of fluidized craters on Mars (revised from Mouginis-Mark, 1979), showing the three proposed sampling sites : Coprates (C), Lunae Planum (L), and Hesperia Planum (H).

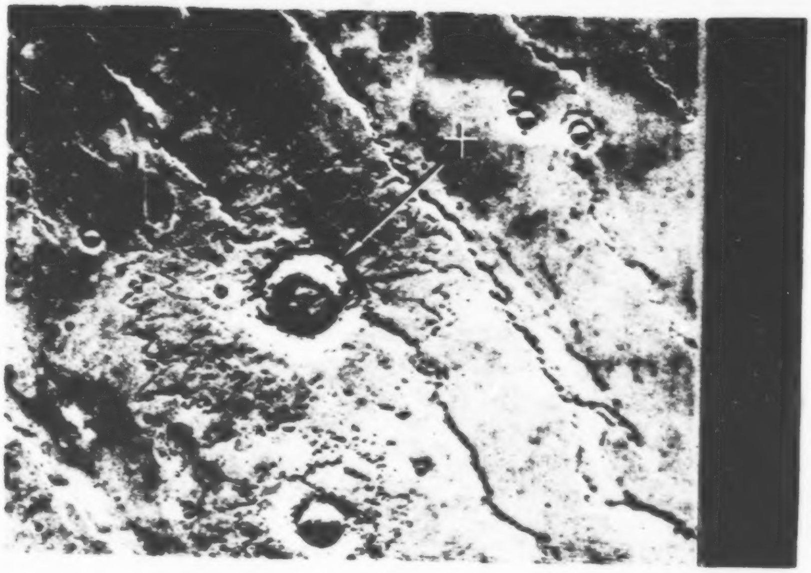

Figure 3.

Ridges and fluidized craters in the Coprates region of Mars. Suggested landing site (+) and sampling traverse (arrow) are shown.
(Viking frame # 608A45).

MARS SAMPLE RETURN MISSION: WHAT LEVEL OF COMPLEXITY?

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The complexity of the U.S. Sample Return Mission is ultimately dependent on current mission funding and the projected direction of the U.S. space program. Despite these uncertainties, it is important to examine mission scenarios to address desired scientific objectives that can be summarized in the following general list:

- Determine existence of climatic records in geologic records.
- Does Mars have a subpermafrost ground water system?
- Fundamental questions on the existence of Mars biology.
- What is the internal structure of Mars?
- Determine the systems for regolith formation.
- What is the contribution of meteorites to Martian geology and climate.

To address these objectives, the sample size, quantity and location must be established and whether this should be the only data searched for on the Martian surface. With this in mind, three mission scenarios are briefly discussed below, in order of increasing complexity.

SCENARIO A

This mission incorporates the use of a rover weighing 454 kg. with a travel range of 50-to-100 kilometers. Rover travel ranges need never exceed these distances to satisfy a significant number of objectives, given landing sites offering a variety of terrain in close proximity to safe landing areas. To simplify rover design many experiments (i.e. spectral, atmospheric) could be conducted from the lander [3].

SCENARIO B

This mission combines the rover in Scenario A with a combination helium-hot air balloon with instrumentation, traveling at an altitude of 4 kilometers during daylight hours [1]. The balloon craft is used augment and extend the rover mission. After performing low altitude photography of candidate landing sites prior to rover touchdown, the suspended instrument package would then move on to examine more distant features accessible via prevailing wind currents. Data from the Viking probes on atmospheric circulation is sufficient to plan such a balloon mission [4,6,7].

SCENARIO C

This mission combines the hardware of Scenario B with the use of a small, 226 kg. hydrazine powered aircraft [2] capable of staying aloft for as long as 30 hours. The balloon craft is used to place a small instrument package on the northern polar cap for sample boring, then continue on to low altitude photography of Martian features. This aircraft using an exaggerated wingspan flying at low altitudes in the denser atmosphere would examine specific features inaccessible by balloon due to wind patterns. Controlled flights along the length of the Valles Marineris or around the peaks of Tharsis Mons could be carried out.

Where the Mars initiative will fit into our space programs long range planning and budget is central to determining the scope of the sample return mission. If it appears that there will be a number of opportunities for robotic missions, then the less complex missions are in order. If, on the other hand, political and budgetary constraints reduce the Mars initiative to one robotic mission prior to a manned launch, we should bring back as much information as possible from that mission[5]. The scientists and space craft builders of NASA have successfully designed and built the most advanced robotic spacecraft ever conceived by man. No mission scenario is beyond the reach of the United States space program.

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N89-18306

MARTIAN REGOLITH GEOCHEMISTRY AND SAMPLING TECHNIQUES; B. C. Clark, Planetary Sciences Laboratory (0560), Martin Marietta Astronautics, Denver, CO 80201

Laboratory study of samples of the intermediate and fine-grained regolith, including duricrust peds, is a fundamental prerequisite for understanding the types of physical and chemical weathering processes on Mars. The extraordinary importance of such samples is their relevance to understanding past changes in climate, availability (and possible physical state) of water, eolian forces, the thermal and chemical influences of volcanic and impact processes, and the inventory and fates of martian volatiles. Fortunately, this regolith material appears to be ubiquitous over the martian surface, and should be available at many different landing sites.

Viking data has been interpreted to indicate a smectite-rich regolith material[1], implying extensive weathering involving aqueous activity and geochemical alteration[2]. An all-igneous source of the martian fines has also been proposed[3]. The x-ray fluorescence measurement data set can now be fully explained in terms of a simple two-component model. The first component is silicate, having strong geochemical similarities with Shergottites, but not other SNC meteorites. The second component is salt[4]. Variations in these components could produce silicate and salt-rich beds, the latter being of high potential importance for microenvironments in which liquid water (brines) could exist. It therefore would be desirable to scan the surface of the regolith for such prospects.

It is also important to sample the regolith with depth. Although Viking sampling to 22 cm resulted in no significant difference in composition of fines, soil horizons may exist below drifts. Permafrost ice may be present within one meter of the surface at intermediate to high latitudes. Because detection and recovery of ice-laden material would be of enormous consequence, not only for scientific reasons but also for future missions to Mars, geologic settings where near-surface ice is expected are essential for the sample return mission.

Core drills for regolith and bedrock sampling on Mars have received preliminary study[5,6]. An independently programmable rotary percussive (IPRP) drilling technique is envisioned for maximum versatility and reliability. Detailed thermal calculations indicate that sample heating should be acceptable or totally negligible. Methods for core removal or sub-sampling have also been investigated. Drive tubes, scoops, and other regolith sampling approaches provide methods of acquisition of duricrust, magnetic material, particle size splits, suspended dust, and saltating grains. Packaging and protection of an indeterminable variety of sample sizes and types will require a versatile return canister, such as stacked hexagonal containerization. Preservation of heat-labile phases (ice, hydrated minerals, etc.) will require careful thermal design and may be benefited by a single or tandem phase-change buffers.

An advanced x-ray fluorescence device can accomplish continuous geochemical monitoring of the surface for compositional changes in regolith and rock fragments, as well as provide for near-range hazard monitoring[7]. Such a unit can almost immediately obtain strong evidence bearing on the geochemical homology (or lack thereof) between SNC meteorites and martian samples, via quantitative analyses for Mn, Cr, and Ni (and other elements) and will be extremely useful for screening all samples to maximize the diversity of the returned sample suite.

If the returned samples require biological sterilization, a non-thermal technique for accomplishing this action has received preliminary study.

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N89-18307

LUNAR PLACEMENT OF MARS QUARANTINE FACILITY; James E. Davidson, Space Services Incorporated and W. F. (Mitch) Mitchell, Lady Base One Corporation

Advanced mission scenarios are currently being contemplated that would call for the retrieval of surface samples from Mars, from a comet, and from other places in the solar system. An important consideration for all of these sample return missions is quarantine. Quarantine facilities on the Moon offer unique advantages over other locations.

Apollo astronauts and their samples underwent lengthy quarantine on Earth. No organic materials where present in their samples, and the astronauts were not exposed to any disease vectors. However, the surface of other planetary bodies in our solar system may not be as free of organic materials as is the Moon.

Mars may or may not contain life forms. Certainly, the Viking landers revealed complex chemistry in the samples they analyzed. The Viking lander data represents isolated samples from two locations. Other planetary bodies present an unknown potential for the presence of organics.

Given that organic compounds, or even living organisms such as viruses or bacteria, may exist on retrieved samples, these samples pose a threat to the Earth's ecosystem. Lack of quarantine restrictions in the fifteenth through nineteenth centuries led to the rapid spread of diseases when European colonists came in contact with natives. In some cases, whole populations were eliminated due to their total lack of immune defenses for certain diseases.

Quarantine facilities on the Moon offer significant advantages over facilities located elsewhere. Orbital quarantine facilities pose a threat of contamination if their orbits degrade. Orbital quarantines would not offer conditions very much like the surface of a planet. Microgravity is known to induce unusual reactions in complex life forms. It might have an equally unusual affect on unknown life forms.

The Moon offers gravity, distance, and vacuum. It is sufficiently near the Earth to allow rapid resupply and easy communication. It is sufficiently distant to lessen the psychological impact of a quarantine facility on Earth's human inhabitants. Finally, the Moon is airless, and seems to be devoid of life. It is, therefore, more suited to contamination control efforts.

Contamination control may require the complete eradication of the quarantine facility. Such a solution would be difficult at best if debris from the facility could decay from orbit and return to Earth. On the Moon, no such difficulty exists. Even if fully staffed bases exist in several locations on the Moon, it is sufficiently vast to avoid interference between the activities of the quarantine facility and those of commercial or other settlements.

N89-18308

GLASS: A SOURCE OF DATA LEADING TO CONSTRAINTS ON THE VOLCANIC, IMPACT, AND ATMOSPHERIC HISTORIES OF MARS.

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Volcanism and impact are important processes on Mars. Both mechanisms can produce glasses. Criteria exist for distinguishing between impact glasses and volcanic glasses [1]. Owing to the single-phase nature of glass, tiny pieces (~ 50-microns diameter) are as compositionally representative as larger pieces, in contrast to multi-phase crystalline samples, such as basalts. The thesis of this abstract is that glasses may be common in the Martian regolith and should be a high-priority sample owing to their combination of (a) low representative mass and (b) high content of information.

Impact glasses: The chemical composition of impact glasses is governed, in part, by the nature of components in the target. Experience with impact glasses on the Earth [e.g. 2] and the Moon [e.g. 3] has demonstrated that important constraints on the chemistries of crustal lithologies in the target can be extracted from analysis of impact glasses. Since these glasses can be ballistically transported tens- to hundreds- of kilometers from their site of formation, a detailed sampling of impact glasses contained in regolith at a single location could provide data on the regional lithologic diversity of the Martian crust. If, for example, carbonates are a significant component in the Martian crust [e.g. 4], chemical systematics in the impact glasses would reflect that fact.

During impact fusion, Martian atmosphere would be implanted into the glass [5]. Chemical and isotopic analysis of glasses produced in many events during a large interval of time could record the isotopic evolution (e.g. $^{15}N/^{14}N$) of the atmosphere. For example, it would be worthwhile to learn the history of increase in $\delta^{15}N$ that has brought it to the present value of 620 ± 160‰ [6]. While trapped atmosphere in impact glasses of different ages could furnish constraints on the rate of exospheric nitrogen loss as a function of time, major volcanic episodes of degassing might also be evident. For example, Figure 1 illustrates a purely hypothetical case involving (a) the episodic injection of "fresh" nitrogen from the Martian interior into the atmosphere during large volcanic events (b) superimposed on the mass fractionation of nitrogen produced by exospheric loss. If primordial Martian nitrogen has a $\delta^{15}N < 0$ [7], then episodic degassing (i.e. volcanism) should be evident in a plot showing the development of the atmospheric $\delta^{15}N$ through time. In this way, impact glasses could be used to infer the ages of major volcanic episodes on Mars involving $\geq 10^6$ km^3 of lava, regardless of whether igneous rocks produced during those eruptions were ever sampled. Major volcanic episodes would show up as a decrease in the atmospheric $\delta^{15}N$ (Figure 1). This is conceptually analogous to using temporal variations of $^{87}Sr/^{86}Sr$ in the Earth's hydrosphere [e.g. 8] to infer the history of seafloor volcanism.

The flux of meteorites and comets onto the Martian surface could be estimated using ^{40}Ar-^{39}Ar ages individually acquired on hundreds of impact glasses. Histograms of impact ages could be used to decide whether the flux was modulated on 30 Ma cycles or was steady-state.

Volcanic glasses: Pyroclastic volcanism [e.g. 9-11] involving, in some instances, low-viscosity magmas [9] may have produced volcanic glass spherules. Samples of rapidly erupted and quenched magmas would be good candidates for primary liquids that could provide major petrologic constraints on the nature of the Martian mantle. Measurements of the Fe^{3+}/Fe^{2+} ratio in volcanic glasses would give limits on the oxidation state of the planet's interior [e.g. 12].

Vesicles in the volcanic glass would contain primordial gas from the mantle [e.g. 13]. In addition, $^{40}Ar-^{39}Ar$ ages acquired on individual pieces of volcanic glass could yield data on the planet's volcanic history. Judging from the high K/La ratios observed in SNC meteorites [14,15], the abundance of K should be sufficient to acquire $^{40}Ar-^{39}Ar$ ages on individual, 100-micron diameter spherules. Finally, mantle xenoliths and xenocrysts might also be found to be associated with the volcanic glasses produced during pyroclastic eruptions.

Sampling strategy: To acquire first-order constraints on Martian history using glasses, mobility of a lander/sampler spacecraft over the surface of Mars need not be a major design-feature. Rather, an efficient retrieval of glasses contained in perhaps about 10-20 kg of regolith at a single site may be capable of providing an adequately diverse suite of glasses.

Problems: The most severe problem menacing the scientific potential of glasses is their survivability in the Martian environment against chemical weathering [16,17]. At present, the proportion of glasses that could survive 1 to 2 Ga is unknown. The scientific potential of Martian glasses for providing significant constraints on the mantle, crust, and atmosphere is proportional to their survival-time against weathering.

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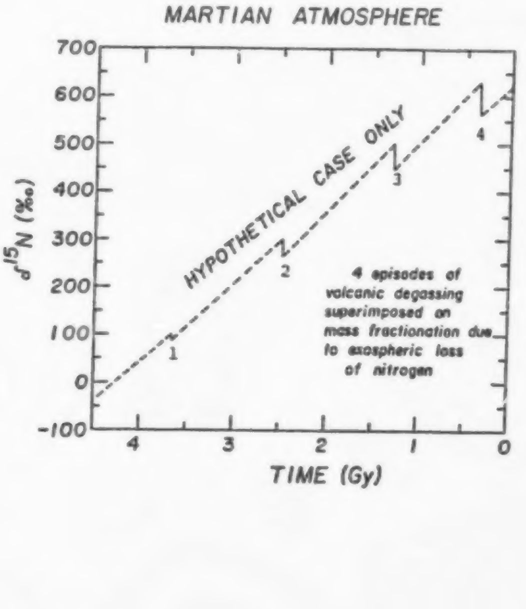

THE ISOTOPIC AND CHEMICAL EVOLUTION OF PLANETS: MARS AS A MISSING LINK;

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The study of planetary bodies has advanced to a stage where it is possible to contemplate general models for the chemical and physical evolution of planetary interiors, which might be referred to as UMPES (Unified Models of Planetary Evolution and Structure). UMPES would be able to predict the internal evolution and structure of a planet given certain input parameters such as mass, distance from the sun, and a time scale for accretion (1,2). Such models are highly dependent on natural observations because the basic material properties of planetary interiors, and the processes that take place during the evolution of planets are imperfectly understood. The idea of UMPES was particularly unrealistic when the only information available was from the earth. However, advances have been made in the understanding of the general aspects of planetary evolution now that there is geochemical and petrological data available for the moon and for meteorites (2,3).

The difficulty in constructing UMPES is that planetary behavior is complicated by the fact that the interiors are at temperatures and pressures where phase changes (including melting) are common and because the differences in density that contribute to the stability of individual structural states of the planet are about as dependent on chemical composition as on phase transitions (4). In addition, the distribution of chemical elements in the solar system at the time the planets were forming, the nature of the accretion process (5, 6) and its effect on the net composition of the planet (particularly the volatile content), the degree of retention of gravitational energy from accretion (1), the rheology of the planetary interior and the efficiency of transport processes within the planet (7), and other factors are all still sufficiently unknown that new observations have a large effect on our understanding of the planetary evolution process.

Despite the complications there are some parameters that are generally agreed to be important determinants (2). Planet size is important because it determines the initial heat budget and the length of time needed for cooling. Distance from the sun also appears important because it is related to the accretion temperature and thus to the ratio of volatile-to-refractory elements in the planet. Observations of the moon have greatly helped in addressing the planet size problem (1,2,3), but even so there are doubts that the moon's origin is typical of planetary bodies in the solar system. The distance parameter has not been seriously tested.

Mars represents a serious test of all aspects of the current understanding of planetary evolution. The body is both smaller than the earth and accreted at a different distance from the sun. Its internal volatile content appears to be different from that of the earth and moon (8). The combination of differing chemistry and gravitational field makes it likely that the nature of its internal chemical diffentiation is substantially different from that of the earth (9). It appears to have had a considerably longer geological lifetime than the moon, but one that is shorter than that of the earth (10).

A valid question with regard to a Mars sample return mission concerns how a limited sampling of the planetary surface could be sufficient to make substantial headway against the complexities of a planet's evolution. However, the answer with regard to geochemistry is that there are certain fundamental properties of the planet that can be deduced from a few carefully chosen samples. The geochemical studies of the moon provide an adequate example of the power of the techniques (1,2,3,11).

Two particularly important and straightforward questions about Mars are 1) How old is the Martian crust? (or What is the mean age of Martian crust-mantle differentiation?), and 2) How differentiated is the Martian mantle? These questions could be answered to first order by as few as two samples. For example, a landing site near the fringes of Olympus Mons could allow sampling of the lavas of the volcano and sampling of both rock outcrop and wind-blown dust from the pre-volcanic basement. With isotopic measurements of Sm-Nd, U-Pb, Rb-Sr, Lu-Hf, and K-Ca, it should be possible (in addition to determining an age for Olympus Mons) to use the isotopic composition of the lava to understand the mean state of differentiation of the Martian mantle, and use the dust sample (partly corroborated by an outcrop sample) to determine the mean age of the Martian crust. If a similar experiment were done for the earth, using a sample of typical mid-ocean ridge basalt and a sample of loess from almost anywhere on the earth's surface (12,13), the deduced values for the mean age of the continents and the crust/mantle mass ratio would be correct to as well as we currently know them; and the need for heterogeneity in the earth's mantle and for an early degassing of the earth (14,15) would be apparent. Consideration of the trace element chemistry of Olympus Mons lava would tell much about the composition of the planet, relating to the effect of heliocentric distance and planetary composition, and the trace element fractionations deduced by comparing the chemical composition of the lava to the initial isotopic ratios of Sr, Pb, Nd, Hf, Ce, Ca, and so on, would elucidate aspects of the mineralogy of the mantle and of magma genesis in Mars.

Clearly, more extensive sampling would be desireable to gain confidence in the interpretations and to understand the petrogenetic evolution of a Martian volcano and the degree of heterogeneity of the crust. Nevertheless, existing isotopic and geochemical methods would certainly yield strong constraints on Martian evolution and would greatly enhance our understanding of several general aspects of planetary evolution.

Existing data on SNC meteorites (16), thought to have come from Mars (17), suggest that Martian internal evolution might not fit very cleanly into the existing framework of solid earth evolution. Trace element fractionations and their relation to isotopic systematics are greatly diffent from typical terrestrial rocks (18). Fundamental parameters like the oxygen isotopic composition are different (19). Interpretation of many aspects of the meteorite data, however, are difficult because of shock effects; and there is of course no guarantee that they are in fact from Mars. Nevertheless, some of the properties would have been predicted, such as the low U/Pb ratio (20) and high Rb/Sr ratio (18) of the sources of the "Martian" igneous rocks.

A sample return from Mars would be one of the most exciting possible developments in planetary science from a geochemical viewpoint. Geochemical tools and analytical capabilities are sufficiently well developed to extract an enormous amount of unique information from even a few small samples of Martian rock.

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SEARCH FOR MARTIAN FOSSIL COMMUNITIES: SCIENCE STRATEGIES, SEDIMENT SITES, AND SAMPLE HANDLING. David J. Des Marais, NASA, Ames Research Center, Moffett Field, CA 94035, U.S.A.

The strategy for locating and sampling possible fossilized Martian organisms benefits from our experience with fossil microbial ecosystems on Earth. Evidence of early life is typically preserved as stromatolites in carbonates and cherts, and as microfossils in cherts, carbonates and shales. Stromatolites, which are laminated flat or domal structures built by microbial communities, are very likely the oldest and most widespread relics of early life. These communities flourished in supratidal to subtidal coastal benthic environments, wherever sunlight was available and where incoming sediments were insufficient to bury the communities before they became established. A logical site for such communities on Mars might be those areas in an ancient lake bed which were furthest from sediment input, but were still sufficiently shallow to have received sunlight. Therefore, although some sites within Valles Marineris might have contained ponded water, the possibly abundant sediment inputs might have overwhelmed "stromatolite-like" communities. Localized depressions which acted as catchment basins for ancient branched valley systems (see S. Squyres' abstract, this volume) might be superior sites. Perhaps such depressions received drainage which, because of the relatively modest water discharges implied for these streams, was relatively low in transported sediment. Multiple streams converging on a single basin might have been able to maintain a shallowwater environment for extended periods of time.

Although stromatolites are recognized as such by their striking laminated fabric, this fabric can resemble nonbiogenic deposits such as travertine, tufa, varves, etc. In order to identify conclusively a "Martian stromatolite" by its morphology, it might be necessary to bring back an intact rock or sediment sample measuring at least several centimeters in dimension. With such a size, fabrics such as those formed by microbial activity (e.g., phototaxis, the light-seeking migration of cells) might be identified.

Perhaps most valuable will be the chemical and isotopic criteria employed for identifying any Martian fossil life. Either organic matter or the minerals affected by biological activity could offer important clues about such life. Archean-age (>2.5 Ga old) Martian sediments probably have experienced less heating and pressure than have Archean sediments on Earth. If Martian microbial communities indeed ever existed, their remains have very likely been preserved in exquisite detail. Therefore during sampling and return to Earth, fossil material must be shielded from light, high temperatures, oxidation, etc., which might damage this evidence.

Below are summarized the basic science objectives as well as sampling requirements.

Science questions. We should seek to understand, in the most general sense, the low temperature ($<200^{\circ}C$) chemistry of the "biogenic" elements (C, H, O, N, S and P) on the surface of Mars. Special emphasis is given to those chemical processes which occurred early in the planet's history. A search for organic matter should receive special effort. By interpreting the chemical and isotopic signatures imposed by nonbiological physicochemical Martian processes, we will help to define the planet's early environment. This effort clearly will assist any reconstruction of a putative ancient biosphere. We would then look for distinctive recurring patterns, among the biogenic elements and their compounds, which might reflect biological processes. Examples of such evidence are those obvious features (cells, stromatolite-like structures, organic matter) which on Earth constitute classical expressions of fossil life.

Nature of Samples. Most interesting are materials which have contacted water and reflect aqueous chemical processing. Accordingly, desirable samples contain minerals precipitated from aqueous solutions at ambient temperatures. Examples include carbonates, silica, and other evaporitic minerals occurring either as whole rocks or as cements. Samples should have experienced low thermal histories subsequent to their deposition, because compounds and minerals indicative of life are temperature sensitive. Ideal are samples derived from shallowwater environments which had received minimal inputs of clastic material.

Sample Masses. This requirement reflects the need to obtain a sample sufficiently large to examine the textures and other physical relationships between the various minerals. For chemical and isotopic studies, a 1 to 5 g sample is desirable. For studies of morphologic features (e.g., stromatolite-type fabrics) 10's of g are necessary.

Optimal sample sites. This requirement follows from the above requirement that the sample should have experienced liquid water. Any site which evidences the effects of liquid water is desirable. Ideal are sites of ancient, shallowwater pools, or sites where low-temperature aqueous chemical precipitation had occurred.

Sample collection procedure. It is critical to circumvent surface dust and crater ejecta which have been heavily altered by weathering and other processes presently active on the planet. This might be achieved either by coring or by sampling ancient strata exposed by weathering or crustal movement. Because the roving sampler must discard most of the samples it inspects, it must be able to screen samples based upon visual appearance, light element content and how well they represent the local rock types. The original in situ sample orientation must be recorded.

Curation. To preserve potentially well-preserved features of biological interest, the samples should be stored at ambient temperatures and be sealed in the ambient atmosphere. Physical disruption must be minimized.

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ACCRETION AND PRIMARY DIFFERENTIATION OF MARS.

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Introduction: In collecting samples from Mars to address questions such as whether Mars accreted homogeneously or heterogeneously, how Mars segregated into a metallic core and silicate mantle, and whether Mars outgassed catastrophically coincident with accretion or more serenely on a longer timescale, we must be guided by our experience in addressing these questions for the Earth, Moon, and igneous meteorite parent bodies.

Accretion and Core Formation: A key measurement to be made on any sample returned from Mars is its oxygen isotopic composition. A single measurement will suffice to bind the SNC meteorites to Mars or demonstrate that they cannot be samples of that planet. A positive identification of Mars as the SNC parent planet will permit all that has been learned from the SNC meteorites to be applied to Mars with confidence. A negative result will perhaps be more exciting in forcing us to look for another object that has been geologically active in the recent past. If the oxygen isotopic composition of Earth and Mars are established to be distinct, accretion theory must provide for different compositions for two planets now separated by only 0.5 AU [1].

Tracing core formation and the homogeneous or heterogeneous nature of accretion can best be accomplished using siderophile and chalcophile elements. Siderophile elements which are compatible in silicate solids in the absence of metal are retained in mantle samples during magma genesis. Only on Earth have samples of known mantle origin been analyzed and interpreted in terms of core formation and accretion processes (e.g., [2, 3]). Interestingly, noble siderophile element abundances in these mantle samples are significantly higher than would be expected to be in equilibrium with a metallic core, based on known metal/silicate partition coefficients. This observation is open to various interpretations (e.g., heterogeneous accretion of the Earth and inefficient core formation - [4, 5]). Such samples would be of utmost importance to collect if they could be identified.

However, it is problematical that mantle samples can be identified and collected using a remote sensing roving vehicle on Mars. More probably, we will successfully collect basaltic materials. Siderophile elements which are incompatible in silicate solids in the absence of metal are concentrated in basalts during melting of planetary mantles. The correlation of the abundances of moderately siderophile elements such as W, P, and Mo with a lithophile incompatible element of equivalent incompatibility has been used in concert with experimental measurements of metal/silicate partition coefficients to successfully recover details of core formation processes in the Earth, Moon, Eucrite Parent Body, and SNC Parent Planet (e.g., [6-13]). Figure 1 illustrates the principle of this method. One possible interpretation of these studies is that the Earth accreted heterogeneously [5] while the SNC Parent Planet accreted homogeneously [12, 13]. If the SNC meteorites are confirmed to be from Mars as a result of a Mars sample return mission, this interpretation raises the question of why two planets so closely associated in space should have accreted differently.

Atmospheric Outgassing: Allegre *et al.* [14] have argued plausibly that the isotopic composition of xenon in various Earth reservoirs is best interpreted in terms of early catastrophic outgassing of at least part of the atmosphere. Briefly, mid-ocean ridge basalts (MORB) have excess ^{129}Xe relative to the atmosphere and to ocean island basalts (OIB). MORB is thought to sample the upper mantle of the Earth, while OIB may sample a deeper reservoir. The excess ^{129}Xe is interpreted as the decay product of ^{129}I. The upper mantle is interpreted to have been efficiently outgassed while ^{129}I was still alive (halflife = 17 x 10^6 years), allowing more ^{129}Xe to be produced in a Xe deficient upper mantle. If similar events occurred on Mars, a sample of the atmosphere and of representative mantle reservoirs might also reveal the signature of early catastrophic outgassing. Whether such outgassing occurred on Mars is problematical, but one way to reconcile the possibility of a heterogeneously accreted Earth with a homogeneously accreted Mars as discussed above would be for Mars to accrete heterogeneously while simultaneously being very effectively homogenized. Such a postulated homogenization process would likely involve very energetic processes which might lead to efficient outgassing. Thus, probing the timing of outgassing might also provide evidence concerning the accretional and primary differentiation processes occurring on Mars.

Sampling Recommendations:

1. To confirm or disprove the link between the SNC meteorites and Mars, any sample with sufficient oxygen to permit precise measurement of ^{16}O, ^{17}O, and ^{18}O and which is substantially uncontaminated with exogenous material will suffice.
2. To address the major questions posed concerning the nature of accretion and the processes of core formation, the samples most likely to be accessible and collectible are fresh basalts. It will be necessary to collect various types in order to populate Figure 1.
3. To address the question of the abundances of compatible siderophile and chalcophile elements in Mars, with implications for accretion and core formation, a major target of opportunity would be the identification and collection of a mantle nodule or of exposed ultramafic terrain.
4. To address the question of the timing and nature of atmospheric outgassing, a sample of the atmosphere of sufficient mass to permit the determination of the abundances and isotopic composition of at least C, N, O, and the noble gases must be collected.
5. The most promising locations to collect samples to address these questions are in the northern plains, which contain the youngest volcanic units.
6. The masses of samples to be returned depends on grain size (excepting the atmosphere, of course) and probably exceeds 1g per sample.

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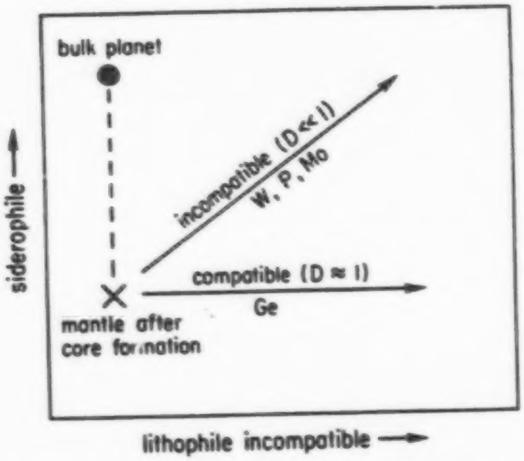

Figure Caption. Schematic diagram illustrating the evolution of elemental abundances of siderophile elements from bulk planet through core formation and subsequent igneous differentiation events over the planet's history. D is the mean mantle/magma partition coefficient of an element.

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PENETRATOR ROLE IN MARS SAMPLE STRATEGY

Steve Dwornik, William Eckstrom, David A. Roalstad

The application of the penetrator to a Mars Return Sample Mission (MRSM) has direct advantages to meet science objectives, and mission safety. Based upon engineering data and work currently conducted at Ball Aerospace Systems Division for Dr. William Boynton at the University of Arizona, who is the Principal Investigator on the CRAF penetrator experiment, the concept of penetrators as scientific instruments is entirely practical.

The primary utilization of a penetrator for MRSM would be to optimize the selection of the sample site location and to help in selection of the actual sample to be returned to Earth. Its recognized that the amount of sample to be returned is very limited, therefore the selection of the sample site is critical to the success of the mission. The following mission scenario is proposed to help solve this problem.

The site selection of a sample to be acquired will be performed by science working groups. A decision will be reached and a set of target priorities will be established based upon data to give geochemical, geophysical and geological data. The first task of a penetrator will be to collect data at up to 4 - 6 possible landing sites. The penetrator can include geophysical, geochemical, geological and engineering instruments to confirm that scientific data requirements at that site will be met. This in-situ near real time data, collected prior to final targeting of the lander, will insure that the sample site is both scientifically valuable and also that it is reachable within limits of the capability of the lander.

Once the penetrator verifies that both criteria are met, it can be used as a homing landing beacon for the lander. Technology for guidance of the lander to the precise sampling site is well within the state of art. After the penetrator has safely guided the lander, it could provide a navigation reference to the rover that will acquire the samples. The penetrator, with stereo capability, can obtain large scale, multispectral images to provide scientists with pinpoint location of sample sites. This mode of operation on the surface can decrease dependency upon artificial intelligence and robotic systems of the rover and therefore provide increased science payload.

PENETRATOR ROLE IN MARS SAMPLE STRATEGY

Dwornik, S., Eckstrom, W., and Roalstad, D.A.

In summary, the penetrator can be an important integral part of the Mars sampling strategy by providing in-situ data, screening and confirmation data to ground based recommendations; it can act as a lander beacon for the soft landing module for pinpoint landing; and can provide a land navigation technique for the rover sample acquisition traverse. Science return will be enhanced and landing safety will be insured.

INSITU CHEMICAL ANALYSES OF EXTRATERRESTRIAL BODIES

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One of the most important tasks on any sample return mission will have to be a quick sample characterisation in order to guarantee a variety of collected samples. An alpha particle instrument with alpha, proton and x-ray modes can provide a quick and almost complete chemical analysis of Mars samples. This instrument is based on three interactions of the alpha particles from a radioctive source with matter: elastic scattering of the alpha particles by nuclei (alpha mode), (α,p) nuclear reaction with some light elements (proton mode), and excitation of the atomic structure of atoms by alpha particles, leading to emission of characteristic x-rays (x-ray mode). The first two modes of the instrument provided the first chemical analyses of the lunar surface at three sites during the Surveyor mission of 1967-1968 (1). Since then the instrument has been improved and miniaturised substantially. The instrument and the technique was described in more details by Economou et al (2).

As we have shown in the past, the alpha particle instrument can operate under Martian conditions without any degradation in the performance (2,3). The alpha and proton modes can provide vital information about the light elements, while the x-ray mode with its ambient temperature x-ray detector will be useful for the heavier elements. The excitation of the atomic structure is provided by the same alpha radioactive source that is used by alpha and proton modes or by an auxiliary x-ray source that is selected to enhance the sensitivity to some important geochemical elements.

For the x-ray mode of the alpha particle instrument the cryogenically cooled Si(Li) or Ge x-ray detectors can not be used on Mars because of prevailing conditions there and because cooling cannot be easily provided. For Mars a new type of x-ray detector that can operate at room or near room temperature is needed. We have in the past considered several semiconductor compounds as room temperature x-ray detectors. Mercuric Iodide room temperature x-ray detectors seem to provide the greatest promise for space instruments (4). The improvements in the energy resolution of these detectors over the last few years (currently about 220 eV at 5.9 keV Fe-55 x-ray line) (5,6,7) as well as the demonstration that they can perform under adverse space conditions (8) made HgI2 detectors good candidates to replace cryogenically cooled Si(Li) and Ge detectors in space applications.

The accuracy of the results will depend naturally on the amount of counting time, source strength, detector areas etc. However, an alpha particle instrument can be modified and designed to give enough accuracy for many critical elements in order to accurately characterise Mars samples in a relatively short time.

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COSMOGENIC NUCLIDES IN THE MARTIAN SURFACE: CONSTRAINTS FOR SAMPLE RECOVERY AND TRANSPORT

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Stable and radioactive cosmogenic nuclides and radiation damage effects such as cosmic ray tracks can provide information on the surface history of Mars. A recent overview on developments in cosmogenic nuclide research for historical studies of predominantly extraterrestrial materials is given in [1].

The information content of cosmogenic nuclides and radiation damage effects produced in the Martian surface is based on the different ways of interaction of the primary galactic- and solar cosmic radiation (GCR, SCR) and the secondary particle cascade. Generally the kind and extent of interactions as seen in the products depend on the following factors: 1. Composition, energy and intensity of the primary SCR and GCR. 2. Composition, energy and intensity of the GCR-induced cascade of secondary particles. 3. The target geometry, i.e. the spatial parameters of Martian surface features with respect to the primary radiation source. 4. The target chemistry, i.e. the chemical composition of the Martian surface at the sampling location down to the minor element level or lower. 5. Duration of the exposure. These factors are not independent of each other and have a major influence on sample taking strategies and techniques.

For stable and radioactive cosmogenic nuclides with half-lives exceeding several thousand years the composition and fluxes of primary GCR and SCR can be considered constant. The composition, energy and intensity of the secondary particle cascade depends on that of the primary radiation, but more so on the composition and geometry of the surface area sampled.

It is therefore important to determine the chemical composition and density of the sampling site. A major factor for the built up and energy distribution of secondary neutrons, the most effective nuclear interactive secondary particles in planetary surfaces exposed to GCR, is the volatile concentration (H_2O, CO_2) of the surface which can vary significantly [2,3]. Especially for core samples, information on the volatile concentration should be preserved in the returned sample throughout all sampling procedures envisioned, or by determination in situ before any volatile expelling procedures (heating) have been applied. Heating, though to a certain extent tolerable, may cause the loss of information from radiation damage effects and some volatile cosmic ray products.

The target geometry places even stronger constraints on sampling strategies and techniques. The built up of the secondary particle cascade in a target and consequently the production rates of cosmogenic nuclides and radiation damage effects are depth and size dependent [2,3]. Therefore, the geometry of any sample taken for cosmogenic nuclide research from the Martian surface has to be preserved and/or documented as precisely as possible. With respect to the thin atmosphere sampling altitude is also an important parameter to account for SCR contributions. Further documentation could consist of in situ measurements of radiation and other parameters of the sampling site such as a neutron depth profile at a core-sampling location, the neutron environment of other sampling locations and the bulk chemical composition and density by means of a gamma-ray survey or other techniques. Additional information on the direct environment of the sample such as the ruggedness of the surface, boulders in close distance, and slopes of the terrain is important.

Another aspect of target geometry has to be seriously considered, if short-lived radioisotopes such as ^{22}Na, ^{60}Co, and ^{3}He will be measured. The circumstances of the Mars-Sample-Return-Scenario include two possible geometry and radiation environment changes, which may influence the information content of short-lived radioisotopes considerably: Sampling and storage in the transportation vehicle and return flight to earth. The constraints derived therefrom are: 1. Samples for cosmogenic nuclide studies shall be taken as late as possible out of their last Martian geometry, i.e. as close as possible to launch date. 2. Samples should be stored in a controlled radiation environment, i.e. active monitoring of the radiation at the sample storage location should be required. 3. Best storage of cosmogenic nuclide samples could be achieved in a container that shields off SCR, but is thin enough not to cause serious built up of cosmic ray secondaries; therefore, this container should be stored away from the spacecraft on passage to earth.

Considering the production mechanisms, samples that provide abundant time information from cosmogenic nuclide studies are cores into soil and dust: maturity and turn over rates can be obtained over short and long time scales. Drill cores into rock, as well as small surface rocks , and top and lateral chips of large boulders give clues on surface exposure and especially on erosion rates. In principle, no surface sample is without time information. As sample geometry is one of the most important factors core samples have to be taken and handled without perturbation of the stratigraphy especially of the top few centimeters until subdivided in a laboartory.

Sample size for a complete consortium study of cosmogenic nuclides and other radiation exposure effects is estimated to be in the few gram range per sample for non-destructive determination of short-lived isotopes; reqirements for destructive analyses are much lower and depend significantly on the extent of the cosmogenic nuclide studies planned. Both, conventional mass spectrometry and especially accelerator mass spectrometry have lowered the limits of detection significantly during the last few years [1]. It can be anticipated that samples of every centimeter from drill cores would be requested at shallow depths, i.e. where major disturbances by aeolian activity are expected, and from every third to fifth centimeter from deeper locations.

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METEORITES ON MARS; G.J. Flynn[1], and D.S. McKay[2], (1) Dept. of Physics, SUNY-Plattsburgh, Plattsburgh, NY 12901, (2) SN4, NASA Johnson Space Center, Houston, TX 77058

Four types of meteoritic material should be found on Mars: 1) micrometeorites, many of which will survive atmospheric entry unmelted, which should fall relatively uniformly over the planet's surface, 2) ablation products from larger meteorites which ablate, break up and burn up in the Mars atmosphere, 3) debris from large, crater forming objects, which, by analogy to terrestrial and lunar impact events, will be concentrated in the crater ejecta blankets (except for rare, large events, such as the proposed C-T event on earth, which can distribute debris on a planetary scale), and 4) debris from the early, intense bombardment, which, in many areas of the planet, may now be incorporated into rocks by geologic processes subsequent to the intense bombardment era.

To estimate the extent of meteoritic addition to indigenous martian material, the meteoritic flux on Mars must be known. Hartmann et. al (1981) estimate that the overall flux is twice that for the Moon and 1.33 that for Earth. For small particles, whose orbital evolution is dominated by Poynting-Robertson (PR) drag (Dohnanyi, 1978), the flux at Mars can be estimated from the Earth flux. The smaller martian gravitational enhancement as well as the decrease in the spatial density of interplanetary dust with increasing heliocentric distance should reduce the flux of small particles at Mars to about 0.33 times the flux at Earth. Because of the smaller planetary cross-section the total infalling mass at Mars is then estimated to be 0.09 times the infalling mass in the micrometeorite size range at Earth.

DIRECT COLLECTION: At Earth the annual infall of meteoritic material hitting the top of the atmosphere is estimated at 16,000 tons, with 12,400 tons of that concentrated in the particles in the 10^{-6} to 10^{-2} gram mass range (Hughes, 1978). These 10^{-6} to 10^{-2} gram particles (from 100 to 3000 micrometers in diameter for density 1 gm/cm^3) are somewhat larger than the micrometeorites. PR drag is not as efficient in altering the orbits of these particles as it is for the micrometeorites, so the 0.09 reduction factor for the micrometeorites most likely serves as a lower limit. Using this lower limit, a minimum of approximately 1100 tons of meteoritic material in the 10^{-6} to 10^{-2} gram mass range would be deposited on the top of the martian atmosphere annually, which, if this mass reached the surface as solid material, would be sufficient to cover the planet with a 3 to 4 cm thick layer over the age of the solar system. (This result would be increased by a factor of 4 if the larger Hartman et al.(1981) flux is used). On earth, particles in this mass range are normally melted or volatilized on atmospheric entry. *However Mars, because of its low gravitational acceleration combined with sufficient atmospheric density to provide deceleration, is probably the most favorable site in the solar system for unaltered survival (and thus collection) of micrometeorites.* We have made new calculations of the interactions of these micrometeorites with the martian atmosphere using the micrometeorite deceleration model first used by Whipple (1950) and the upper atmospheric density profile for Mars derived from Viking entry measurements (Seiff and Kirk, 1976). Particles of the same density, shape, and thermal characteristics entering at velocities near the martian escape velocity are heated to a peak temperature only half that experienced on Earth entry at earth escape velocity. Although most particles larger than 75 to 100 micrometers in diameter are melted on Earth atmosphere entry, the cutoff size for melting on Mars entry would be about 13 times larger, or 1000-1300 micrometers in diameter.

The concentration of micrometeorites in martian soils depends on the fraction of them which survive atmospheric entry as solid material, the regolith depth and the total accumulation time. For illustrative purposes only, we assume that all of the micrometeorites smaller than 3000 micrometers survive atmospheric entry in some form as solid material, the martian regolith has an average depth of 10 m (consistent with Arvidson's (1986) estimate of a planetary meters/10^9 years erosion estimate based on crater preservation), and micrometeorites have been accumulating at the present estimate rate for the past 4 x 10^9 years. For these conditions, a 10 gram average soil sample would have been mixed with about 5000 micrometeorites greater than 100 micrometers in diameter and 10 micrometeorites greater than 800 micrometers in diameter. Micrometeorites in this size range which have survived atmospheric entry are normally not collected at earth. These larger particles from Mars orbital distance are likely to sample different sources than the smaller micrometeorites collected at 1 a.u. in the cosmic dust sampling program on earth (Flynn, 1987; Zook and McKay 1986).

COLLECTING SITES FOR MICROMETEORITES: Martian surface processes (weathering and wind erosion, transport, and deposition) may fractionate the dust by size, density or composition providing regions of increased local concentration, suggesting even more suitable sites for micrometeorite sampling than the average soil. *These sites may include placer catch basins or lag surfaces which may accumulate high density micrometeorites or their derived and altered minerals. Conversely, low density micrometeorites may be wind segregated along with finer martian dust and may constitute a relatively coarse-grained component of that dust at its deposition sites.* By analogy with Antarctica, meteorites of all size ranges may be relatively concentrated in martian polar regions, although the concentrations mechanisms may be different.

MICROMETEORITES AS A TOOL: Micrometeorites added to martian regolith after atmospheric deceleration below hypervelocities may still be identifiable by petrographic or chemical means. While they may be relatively quickly destroyed by martian weathering, the chemical signature, particularly siderophiles, may persist in the soils, as they have in the lunar regolith (Anders et al., 1973). The possibility that detectable micrometeorites and their remains can be found in the martian soils depends on the relative rates of infall, weathering and alteration, transportation, and mixing, and these rates are not yet known reliably enough to allow us to predict with certainty whether identifiable micrometeorites will be found. *However, assuming that micrometeorites could somehow be identified in returned soil samples, this addition of micrometeorite material to the uppermost martian regolith at a constant rate could conceivably provide a powerful tool for tracking rates of erosion, deposition, and weathering.* Some attempt should be made to collect soils from different geologic sites (catch basins, lag surfaces, flat high plains, valley bottoms, etc.) so as to provide a variety of soils of different sedimentary environments. One of the important differences among these environments might be the proportion of petrographically or chemically identifiable micrometeorites mixed into the soil.

MARTIAN AGGLUTINATES: *If, as we calculate, micrometeorites are all slowed down by the martian atmosphere, and assuming that most lunar agglutinates are made by micrometeorite impacts, no analogous martian agglutinates would be expected* (unless there were an era in which the atmosphere was considerably less dense than at present). However, many types of impact glasses would be expected from larger impacts, and some of these glasses may resemble lunar agglutinates in some respects.

MARTIAN SOIL MATURITY: Gault and Baldwin (1970) have estimated a minimum impact crater size of 50 meters, taking into account fragmentation and ablation of the incoming projectiles as well as atmospheric deceleration. The smallest craters noted in Viking orbiter images are about 100 meters in diameter (Blasius, 1976), but smaller craters beyond the resolution limit of the photographs may still be present. Dycus (1969) predicts that projectiles as small as 10 gm would still form craters. However, craters too small to be seen from the orbiter are not apparent in Viking lander images. Impact gardening associated with the 50 meter and larger craters predicted by Gault and Baldwin (1970) would determine regolith turnover rates and cause comminution of rocks into soils. The addition of micrometeorites would affect the petrology and chemistry of martian soil. Weathering and sedimentary processes on Mars would also process the regolith components. The overall effect would be to make an exceedingly complex regolith. *A new maturation scale will be necessary for martian regolith. This scale will have to include terms which reflect (1) impact reworking, (2) addition of micrometeorites, and (3) martian surface weathering and alteration.* For example, if concentration mechanisms can be factored out, the abundance of micrometeorites (identified petrographically or chemically) in a soil layer might be directly related to its near-surface exposure time in a manner analogous to the abundance of agglutinates in lunar soils. In addition to soil evolution through maturation, physical mixing of soils of differing maturities should be common.

The first returned soil samples from Mars should provide the opportunity for recovery and analysis of unaltered micrometeorites larger than any sampled on earth, assessment of the magnitude of the meteoritic component, and possibly an estimate of the rate of erosion and regolith production on the planet. This micrometeorite population may be quite different from the population sampled at 1 a.u. The extent of regolith gardening, small crater production, and agglutinate production (if any) will also provide clues to the evolution of the martian atmosphere density over time.

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N89-18316

TRACE FOSSILS OF MICROBIAL COLONIZATION ON MARS: CRITERIA FOR SEARCH AND FOR SAMPLE RETURN;

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The recent discovery of microbial trace-fossil formation in the frigid Ross Desert of Antarctica suggests that early primitive life on Mars may have left behind similar signatures[1]. These trace fossils are apparent as chemical or physical changes in rock (or sediment) structure (or chemistry) caused by the activity of organisms. Life on Mars, if it ever existed, almost certainly did not evolve above the level of microorganisms, and this should be considered in search for fossil life[2]. For the reasons detailed here, microbial trace fossils seem to be a better and more realistic target for search than would be "true" microbial fossils (remnants of cellular structures):

- Fossil preservation of cellular structures can occur only when a fortuitous combination of certain environmental factors is present. For this reason, fossilization in a cold desert environment such as in the modern Ross desert, or on early Mars, is unlikely to occur or have occurred. Yet, as we now know, trace fossils can be formed even under such conditions.

- There is no cogent reason to assume that biological evolution on Mars resulted in morphologies similar to those on Earth. Therefore, fossil Martian microorganisms may be difficult to recognize, while trace fossils leave simpler and easier recognizable signatures.

- If the size of primitive Martian microorganisms was of the same order of magnitude as their terrestrial counterparts, then the on-site search for fossils involves the recognition of microscopic patterns in the micrometer range, achievable only by highly complex instrumentation. Microbial trace fossils (like those in the Antarctic Ross desert), however, form patterns in the millimeter range and thus offer targets that can be recognized by less complex instrumentation.

- As trace fossils do not contain combustible carbon, the conditions for sample handling, storage, and return are probably less stringent than in the case of true fossils.

The model of the Ross desert trace fossils makes it possible to set concrete aims for the search for past microbial life on Mars. These can be defined as the recognition of chemical and/or physical discontinuities in rocks or sediments that appear to run against, or in no conformity with, apparent physical and chemical gradients and which cannot be explained by chemical and physical gradients.

TRACE FOSSILS OF MICROBIAL COLONIZATION ON MARS:

E. I. Friedmann.

It is suggested that samples of Ross desert trace fossils be used for experimental studies on conditions of sample handling and storage, sample size, as well as for instrument design for collection and on-site recognition.

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[2] Friedmann, E.I. (1987). The Antarctic Cold Desert and the Search for Traces of Life on Mars. Advances in Space Research 6:265-268.

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A MARS ORBITAL LASER ALTIMETER FOR ROVER TRAFFICABILITY: INSTRUMENT CONCEPT AND SCIENCE POTENTIAL; J.B. Garvin and M.T. Zuber, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

Limited information on the types of geologic hazards (boulders, troughs, craters etc.) that will affect rover trafficability on Mars are available for the two Viking Lander sites, and there are no prospects for increasing this knowledge base in the near future. None of the instrument payloads on the upcoming Mars Observer or Soviet PHOBOS missions can directly measure surface obstacles on the scales of concern for rover safety (a few meters). Candidate instruments for the Soviet Mars 92 orbiter/balloon/rover mission such as balloon-borne stereo imaging, rover panoramic imaging, and orbital synthetic aperature imaging (SAR) are under discussion, but data from this mission may not be available for target areas of interest for the US Mars Rover Sample Return (MRSR) mission. In an effort to determine how to directly measure the topography of surface obstacles that could affect rover trafficability on Mars, we are studying how to design a laser altimeter with extremely high spatial and vertical resolution that would be suitable for a future Mars Orbiter spacecraft (MRSR precursor or MRSR orbiter). This report discusses some of the design issues associated with such an instrument, gives examples of laser altimeter data collected for Mars analogue terrains on Earth, and outlines the scientific potential of data that could be obtained with the system.

In contrast with the design of a Lunar Observer Laser Altimeter (LOLA) intended for global profiling of lunar surface topography at 30 m spatial resolution [1], an orbital system appropriate for directly measuring obstacles no larger than a few meters in scale on the surface of Mars must incorporate an extremely high repetition rate laser transmitter into the basic design. From an orbital height of 350 km (MO altitude), a Mars Orbiter Laser Altimeter for Rover Trafficability (MOLAR-T) containing a CW-pumped, cavity-dumped Nd:YAG laser transmitter operating at a pulse repetition rate of 1000 Hz could provide 15 cm vertical resolution contiguous footprints as small as 2 m in diameter along track. The system would also consist of a 50 cm telescope, data system, and suitable sub-nsec time interval unit and constant fraction discriminator electronics. The laser transmitter would emit in the near infrared, thus providing the additional capability of measuring the relative reflectance of Martian surface materials. The instrument would transmit several mjoules of energy per 1-3 nsec (FWHM) laser pulse when operating in full repetition rate mode (a few minutes per orbit if pre-selected candidate target areas are the focus). An alternative design involving larger footprints (say 30 m) with oversampling by a factor of 15 along track could detect meter scale obstacles if signal processing were invoked.

Airborne laser altimeters in operation and under development at GSFC directly simulate some of the key instrument parameters of MOLAR-T. In order to simulate the type of data expected for this instrument from Martian analogue terrains, a 400 Hz Nitrogen laser altimeter system was flown at low altitude over volcanic landscapes in SW Iceland. The instrument and mission configuration provided 1.5 m diameter footprints along track, with oversampling by a factor of five on the basis of aircraft velocity. Figure 1 is an example of a profile obtained with this system for the southern wall of the collapsed vent crater of Surtur II on the island of Surtsey. The profile demonstrates the type of hazard that even a relatively autonomous rover must avoid. The 6 m "cliff" at the edge of the 100 m diameter pit crater has a local slope of 59 degrees, which would not be easily traversed by any sort of rover. Figure 2 is a profile of a boulder-covered beach on the north shore of Surtsey that illustrates the presence and detectability of individual meter-scale boulders.

Our preliminary study suggests that a very high spatial and vertical resolution profiling system would be capable of directly detecting rover obstacles without resorting to model-dependent analyses such as those required for interpretation of microwave and thermal IR surface scattering observations. Profiles from such an instrument could be used in studies of local geomorphology (e.g. lava flow heights, local gradients, etc.) as well as for obtaining "ground-truth" data on surface roughness useful for calibrating microwave and thermal observations. As currently conceptualized, the MOLAR-T instrument would exceed the severe weight, power, and data-rate limitations imposed for Observer-class spacecraft. More rigorous definition of this proposed instrument concept, and continued analysis of Iceland analogue data in the context of Mars rover trafficability are in progress. (We thank J.B. Abshire and J.L. Bufton for many helpful discussions regarding engineering requirements. This work was indirectly supported by NASA RTOPs 157-03-80-20 and 677-43-24.)

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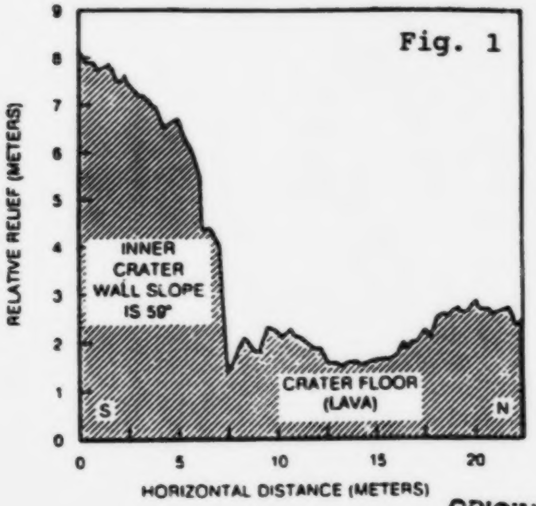
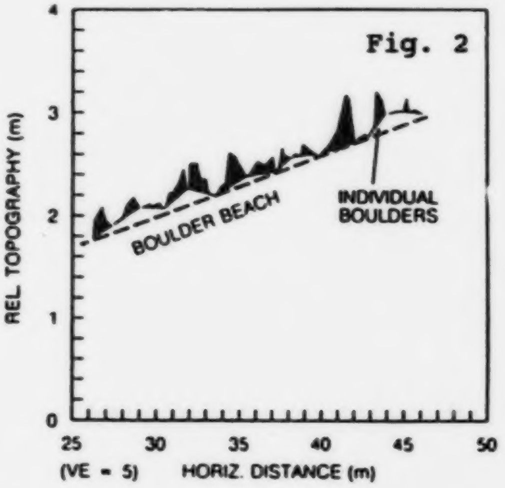
Figure 1. Airborne laser profile (0.25 m effective footprint diameter, 0.3 m vertical resolution, sub-meter after GPS-assisted aircraft motion removal) of the south wall of the vent crater Surtur II on Surtsey, Iceland, obtained from 1200 ft. altitude in the NASA/WFF P-3 aircraft using the 400 Hz AOL laser altimeter.

Figure 2. Laser profile of a boulder-covered beach on the north shore of Surtsey obtained with the same system as in Figure 1. The dotted line shows the local slope of the beach and the solid lines show the positions of meter-scale boulders.





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THE SEARCH FOR AND IDENTIFICATION OF AMINO ACIDS, NUCLEOBASES AND NUCLEOSIDES IN SAMPLES RETURNED FROM MARS

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INTRODUCTION:

The Mars Sample Return mission will provide us with a unique source of material from our solar system; material which could advance our knowledge of the processes of chemical evolution.

As McKay (1) and others have pointed out, on Mars, geological investigations based on the Viking datasets have shown that primordial Mars was in many biologically important ways similar to the primordial Earth; the presence of surface liquid water, moderate surface temperatures, and atmosphere of carbon dioxide and nitrogen, and high geothermal heat flow. Indeed, it would seem that conditions on Earth and Mars were fundamentally similar during the first one billion years or so. As has been pointed out (1), Mars may well contain the best preserved record of the events that transpired on the early planets.

Examination of that early record will involve searching for many things, from microfossils to isotopic abundance data.

We propose an investigation of the returned Mars samples for biologically important organic compounds, with emphases on amino acids, the purine and pyrimidine bases, and nucleosides.

EXPERIMENTAL:

A. Sample extraction

Extraction of these molecules from the returned samples will be performed using the hydrothermal extraction technique described by Cheng and Ponnamperuma (2).

A one to five gram sample of finely divided sample will be placed in a pyrex glass extraction tube, 3 ml of ultrapure water will be added per gram of sample, the tube sealed with a hydrogen-oxygen torch, shaken well, then placed in a 165° oven for 1 hour. All samples processing procedures will be conducted in a clean room.

At the end of this period the tube will be centrifuged and the supernatant removed for analysis. Portions of the extract will be analyzed for amino acids, nucleobases and nucleosides.

B. Analysis of sample extracts

Capillary gas chromatography-mass spectrometry, reversed-phase liquid chromatography, affinity chromatography and capillary GC using chiral phases will all be utilized in these studies. Figure 1 illustrates the separation of amino acid enantiomers by chiral phase capillary GC. Each number on the figure denotes enantiomers of an amino acid (from: Abe, I., in Amino Acid Analysis by Gas Chromatography, Zumwalt, R., Kuo, K. C., and Gehrke, C. W., eds., CRC Press Inc., 1987).

For analysis of the extract for free amino acids or amino acids present in a bound or peptidic form, aliquots will be analyzed by capillary GC/MS both before and after hydrolysis with 6N hydrochloric acid. The extracts will be derivatized to the N-trifluoracetyl n-butyl esters or N-heptafluorobutyryl isobutyl esters and examined for the presence of amino acids by GC/MS.

Establishment of the presence of amino acids would then lead to the next logical step, which would be the use of chiral stationary GC phases to determine the enantiomeric composition of the amino acids present, and thus potentially establish their biotic or abiotic origin.

This investigation will utilize chiral stationary phases such as Chirasil-Val which resolves the enantiomers of amino acids. Bayer *et al.* (3) have recently provided an excellent review of recent progress in separation of amino acid entiomers using chiral polysiloxanes.

Successful examination of the returned Mars samples for the presence of indigenous amino acids and the determination of their enantiomeric composition will obviously require rigorous exclusion of terrestrial contamination, and our study of the returned lunar samples provides considerable background on matters ranging from sample acquisition, processing and handling to evaluation of the purity of reagents and glassware used. Figure 2 illustrates the levels of contamination present in a single fingerprint (4).

Analysis of the returned Mars samples for amino acids, therefore, will require both the use of the best analytical techniques available and the design of experiments in such a way as to avoid contamination and yield the maximum amount of information.

Confirmational analyses for amino acids would include ion-exchange and reversed-phase liquid chromatographic analyses; for example, analyses comparable to our IEC analyses of Apollo 17 samples (Figure 3, references 5-7).

For analyses of the returned Mars samples for nucleobases and nucleosides, affinity and reversed-phase liquid chromatography would be utilized. Figure 4 demonstrates our separation of ribo- and deoxyribonucleosides by RPLC, and Figure 5 shows our separation of some 37 major and modified ribonucleosides. This technology, coupled with scanning UV detection for identification, presents a powerful tool for nucleobase and nucleoside analysis. Mass spectrometric analysis of these compounds would confirm their presence in samples returned from Mars.

SAMPLE TYPES AND QUANTITY:

It is requested that the main samples consist of core samples. The core samples should be taken at up to 5 m in depth. The samples should consist of 20-25 g from each total core sample. The core sample should be subsampled at 10 different depths with 2 g for each subsample. The samples should be protected from extreme heat and radiation, and maintained in a nitrogen atmosphere or atmosphere similar to that of Mars. It is essential that the sample containers be ultraclean, and that the samples be protected from terrestrial contamination.

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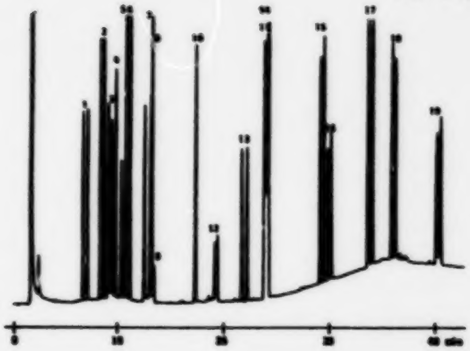

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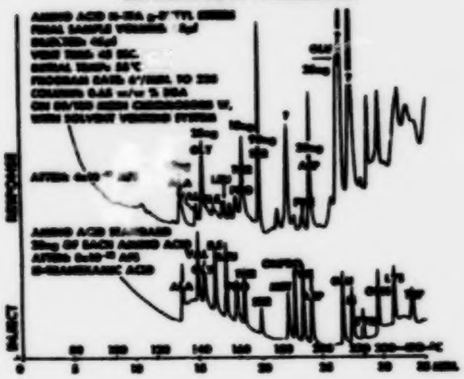

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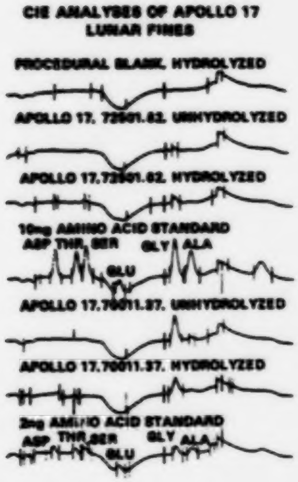

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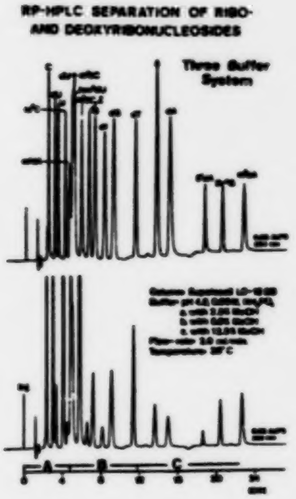

Figure 4.

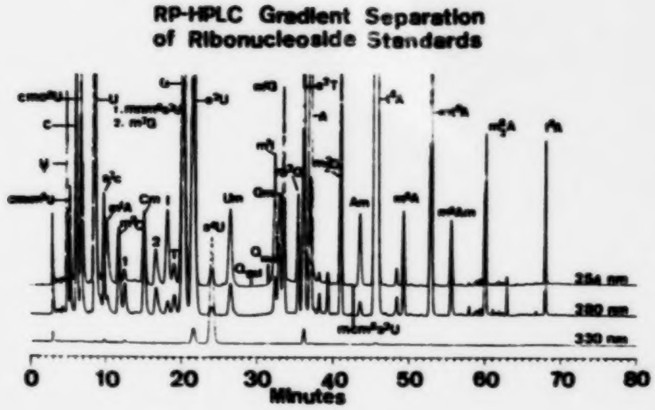

Figure 5.

N89-18319

SOIL DEVELOPMENT AND SAMPLING STRATEGIES FOR THE RETURNED MARTIAN SURFACE SAMPLES. Everett K. Gibson, SN4, Expt. Planetology, NASA Johnson Space Center, Houston, TX.

Sampling of the Martian surface materials should be based upon the experience which has been gained from the study of soils and rocks collected in cold, dry environments-i.e. Dry Valleys of Antarctica. Previous studies (1) have suggested that some of our best terrestrial analogs of the Martian soils are represented by those found in the polar deserts of Antarctica. Special sampling considerations must be taken into account when obtaining these samples because they represent at least five distinct types of materials.

Weathering of planetary regolith materials occurs from both chemical and physical interactions of the planet's surface materials with the atmosphere and, if present, the hydrosphere and biosphere along with extraplanetary objects which may produce cratering. The net result of weathering processes is to modify the original surface materials and produce secondary materials that are products of equilibrium between the atmosphere and interacting particles with the solid body. In order to adequately study weathering processes and regolith development occurring on Martian-like surfaces, simulation studies must be carried out in the laboratory under controlled conditions or study analog materials in the field. Our studies have concentrated on studying soils from the Dry Valleys of Antarctica which are from the Earth's coldest and driest desert. Surface processes operating in the Dry Valleys are similar to Martian surface processes in the following respects: low temperatures (mean temperature of -17^{o}C in Wright Valley), low absolute humidities, diurnal freeze-thaw cycles, low annual precipitation, desiccating winds, low magnetic fields, salt-rich regolith, oxidizing environment and the near absence of biological activity. In the Dry Valleys, physical or mechanical weathering predominates over chemical weathering processes (2). Even though chemical alteration is a secondary weathering process in the Dry Valleys, it is still present and plays an important role in regolith development.

From the studies of the soils and cores collected from the Dry Valleys, an idealized soil profile has been developed for a cold, arid planetary surface similar to what is expected to be present on Mars (excluding the polar regions). The soil profile is composed of five basic zones: an aeolian zone, a salt formation zone, an active zone, a seasonally frozen zone, and a permanently frozen zone. The four zones above the permanently frozen zone are the regions where the majority of the physical and chemical weathering occur. The aeolian zone (upper most region of the soil profile-typically less than 2 cm thick) represents the region where activity is occurring daily. Effects of the surface winds, temperature fluctuations, moisture deposition, and radiation evnironment are recorded within this regolith zone. The salt formation zone represents the area where salts are forming and deposited. Salts are associated with the duricrust and their presence has recently been reviewed (3). The salt zone will typically be located within 5 cm of the surface. The active zone represents the region of transition between the salt zone and the frozen zones where the abundances of surface deposited salts decrease as a function of depth and daily temperature fluctuations and are damped as compared to the upper zones. The seasonally frozen zone represents the region of the regolith which undergoes melting-thawing and freezing, depending upon the season. The permanently frozen zone remains at a temperature below the frost point throughout the Martian year. In such a region ice is stable on a yearly basis. The observed condensates in the Solis Lacus and Noachis-Hellespontus region (4) could easily be accounted for by this model. The movement of moisture through the regolith with subsequent loss to the atmosphere would leave behind those anions and cations which favor salt formation. The seasonal cycling of moisture from the regolith would result in salt-rich deposits near the surface similar to those observed at the Viking sites. Such salt deposits have also been observed in the Dry Valleys of Antarcitca (1).

Sampling experiences obtained from the collection of bulk soils and subsurface cores in the Dry Valleys have shown that it is extremely difficult to obtain samples from the seasonally frozen and permanently frozen zones. Titanium strengthen core tubes which were identical to those used to collect the lunar cores were used to collect soils from the Dry Valleys. In every case where soils from permanently frozen zones were attempted to be collected, the core tubes were damaged during the attempt to collect samples. The cores were driven into the ground using a five pound hammer. The tool-steel strengthen bit and the bottom of the cores were severly damaged and the collection of samples failed to occur in a recoverable manner. If the samples are to be obtained from the Martian regolith in regions where permanently frozen soils might exist, extreme caution must be exercised to prohibit the loss of valuable collection equipment and not damage the vehicle transporting the collecting devices. As demonstrated by the Viking sampling arm, the upper tens of centimeters of the regolith should provide materials from the aeolian, salt, and active regions of the soil profile. However, collection of material from the seasonally frozen and permanently frozen must be undertaken using the utmost caution.

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MARTIAN WEATHERING PRODUCTS AS TRACERS OF CLIMATE CHANGE AND ATMOSPHERE/HYDROSPHERE EVOLUTION ON MARS.

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Introduction. Primary objectives for exploration of Mars include determination of (a) the distribution, abundance, and sources and sinks of volatile materials, and (b) the interaction of surface materials with the atmosphere [1]. Both objectives fall within the purview of planetary surface weathering studies [2] and require documented samples of weathered materials, including rock surfaces, soils, and sediments. Major issues to be addressed in selecting and studying Martian samples in this context are summarized in the following review.

1. What abundances of potential atmosphere- or ocean-forming elements are located in the regolith? *Reversible sinks* include physically condensed species (ground ice, frosts and adsorbed gases) that can recirculate under the influence of diurnal, seasonal, or climatic temperature cycles. In contrast, *irreversible sinks* (hydrated silicates, carbonates, oxides, etc.) are resistant to surface temperature cycles and will return volatiles to global circulation only under extreme duress (e.g., catastrophic meteoroid impacts or volcanic intrusions). First-order goals are to determine the abundance and distribution of ground ice and volatile-bearing secondary minerals as a measure of whether Mars' atmophile-element endowment was sufficient to have once supported a thicker, more Earth-like atmosphere and hydrosphere. Carbonates, for example, are theoretically crucial but unproven sinks for Martian CO_2 [3]. Efforts to detect Martian carbonates by Earth-based remote sensing have not been successful [4] although calcite has been found in at least one SNC meteorite (EETA79001) [5]. *Mars Observer* may be able to detect and map carbonates but direct laboratory study of soils and sediments is the only effective way to determine the times and modes of carbonate formation.

2. Do weathering products of various ages indicate systematic climate changes? In the absence of abundant biogenic fossils, Martian paleoclimates must be deduced from the mineralogical and stable-isotopic compositions of fossil weathering products in soils. Under current conditions on Mars, gas-solid weathering reactions should predominate and few genuine clay minerals should be forming [6, 7]. Some evidence suggests, though, that clay mineral(oid)s might be major components in Martian soils [8], indicating metastable preservation after formation in environments dominated by liquid-solid, water-based reactions. Critical issues are how and when liquid water became available to drive weathering, whether silt- and clay-sized materials contain true phyllosilicates or simply palagonite/allophane phases, and whether substantial quantities of zeolites were formed [9]. Ratios of D/H, $^{13}C/^{12}C$, and $^{18}O/^{16}O$ in secondary minerals should permit calibration of weathering temperatures, provided that isotopic compositions of other participating volatile reservoirs (ground ice, atmospheric water vapor and CO_2, etc.) can also be determined. Exchangeable ions in clay minerals and zeolites would reveal the chemistry of the solutions with which they were last equilibrated. In addition, gases occluded in the same phases might provide samples of the Martian atmosphere as it existed during various weathering epochs. Absence of nitrates and absence of significant $^{15}N/^{14}N$ fractionations by regolith phases must be confirmed as tests for models for atmospheric $^{15}N/^{14}N$ fractionation and their implications for loss of the early Martian atmosphere. Finally, analysis of cosmic-ray-produced particle tracks and nuclides in rock surfaces and layered regolith samples would permit inference of how atmospheric shielding (i.e., density) has changed over time [10]. To date climatic periods, ages of old soils and sediments might be obtained by the Sm-Nd chronometer (Rb-Sr might be too susceptible to disturbance by weathering) whereas younger samples might be dated by the U-Th disequilibrium and ^{36}Cl methods.

3. Did mechanisms and rates of chemical weathering change through time and did they fractionate surface compositions? Martian surface materials receive high doses of ultraviolet radiation [11] and, as either a consequence or coincidence, contain trace quantities of oxidants that react vigorously with water and simple organic compounds [12]. It has been speculated, though not established, that ultraviolet-catalyzed reactions have dominated chemical weathering on Mars [13], including formation of unusual peroxides or superoxides that would destroy Martian organic compounds. Clearly, though, UV-driven reactions can only be important in the outer few micrometers of the Martian surface so that it is imperative to understand whether different weathering processes operate at depth and how styles of weathering might have changed through time. Independent of UV influence, low-temperature weathering can drastically fractionate K from other lithophiles [14], producing misleading impressions of the ^{40}K contents (an index for internal heat generation) of the parental materials. *Mars Observer* will provide global maps of K abundance that can be correctly interpreted only if weathering effects are understood through sample studies.

4. What samples are needed? Paleoclimate studies must distinguish soils from sediments [2], requiring regolith drill-core samples that document the zonal structures and parent/daughter material relationships that are essential features of soils. Interpretation of duricrust genesis (cyclical vs. recent-only processes) must also rely on search for multiple duricrust layers in continuous cores. Process-oriented weathering studies will require chips (or short drill cores) of natural surfaces from large rocks of various types and ages so that contemporary rock weathering can be distinguished from pedogenic or fossil weathering recorded in the regolith. At the minimum, Noachian-, Hesperian-, and Amazonian-age units should be sampled to establish basic weathering and volatile-sink trends through time. In addition, atmospheric dust should be sampled to establish its possible traceability to known units or weathering epochs.

Stable-isotopic and trapped-gas studies of ground ice are essential complements to similar studies of soils. It is doubtful, though, that ground ice can be sampled within a few meters of the surface at any location outside the polar circles. Based on geomorphic evidence, ground ice is rare to absent within ± 30° latitude of the Martian equator but increases in abundance toward the poles [15]. According to model calculations, ground ice could survive on Mars for 10^9 y if covered by at least 10 m of ultrafine-grained and effectively non-porous soil [16]. For all geologically reasonable values of regolith particle-size and porosity, though, diffusion of water vapor from buried ice into the atmosphere should preclude survival of temperate-latitude ground ice over Martian geologic history at any depth shallower than 100 m [17]. Accordingly, acquisition of ground ice samples will probably require a mission to a polar site.

All samples must be protected from thermal degradation and from both pro- and retro-grade, mineral/volatile reactions. Important paleoclimate indicators are expected to be metastable mineral assemblages with stable-isotopic signatures that are susceptible to further atmospheric exchange reactions. An upper limit of 263° K for storage should preserve thermally labile compounds and ice but a design goal of 240° K should be implemented to control desorption and reactivity of atmospheric gases.

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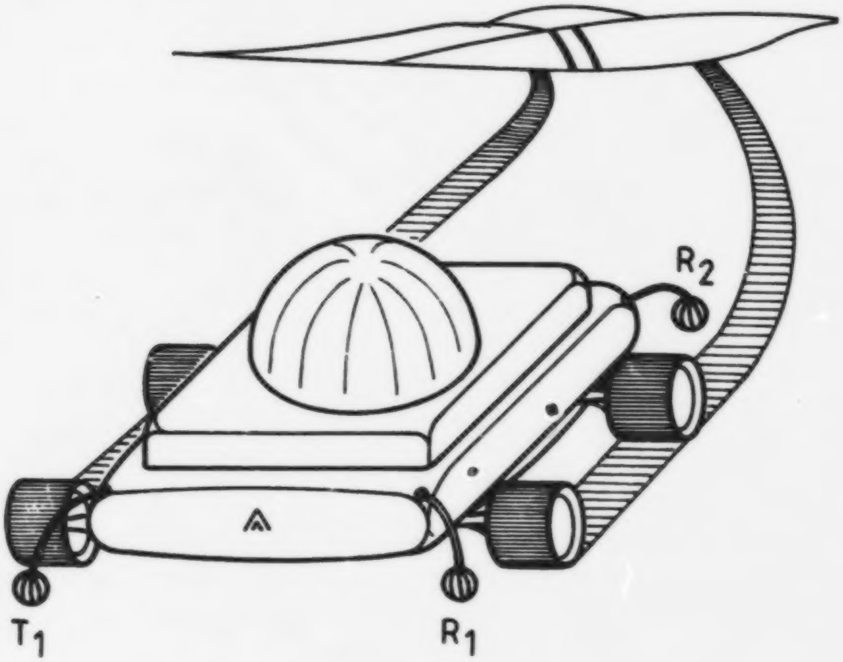
This instrument will measure the resistivity ρ and the relative dielectric constant ε_r of the Martian top soil along the path of a rover. This aim is achieved by measuring the real and imaginary parts of the complex permittivity $\varepsilon = \varepsilon_r - j\varepsilon_i$, where $\varepsilon_i = (\omega\varepsilon_o\rho)^{-1}$; ε_o is the permittivity of vacuum and ω is a variable angular working frequency. The experimental technique consists in evaluating the mutual, or transfer, impedance of a quadrupolar probe, i.e. in quantifying the influence of the Martian ground upon the electrical coupling of two Hertz dipoles. The horizontal and vertical spatial resolutions are of the order of the length and separation of the dipoles, typically 1-2 metres. The four-electrode method for measuring the ground resistivity on Earth has been first applied by Wenner (1) and Schlumberger (2), but the proposed investigation bears more resemblance with a similar instrument which has been developed for ground surveying at shallow depths, in connection with archaelogical and pedological research (3). A quadrupolar probe will provide essential information about the electric properties of the Martian ground and will contribute usefully to the identification of the soil structure and composition in association with other experimental equipments (camera, infra-red detector, gamma and X-ray spectrometers, chemical analyzers, ground temperature probes). Complex permittivity measurements will reveal small scale anomalies caused by discontinuities in surface material distribution, underlying fractures and cavities, burried boulders, etc.., leading to the selection of soil sampling and drilling locations and to the characterization of the site environments. If a sufficient data base can be collected over the entire lifetime of the rover, it will be possible to draw maps of the electric properties of the terrain and compare them with features derived from topological, geological and thermal surveys. If the rover stands at the same location for a period of at least 1 Martian day (1 sol = 24 h 39 mn) or returns to the same site after a period commensurate with a Martian year (669 sols), diurnal and seasonal variations in the distribution of volatiles may give rise to measurable changes of the local complex permittivity. The detection of obstacles (large boulders) or ground level gradients (small craters) out of the field of view of the camera may also support the autonomy and the safe operation of the vehicle. A quadrupolar probe consists of a transmitting dipole (T_1, T_2) and a receiving dipole (R_1, R_2); an alternating current, I_t, is injected between T_1 and T_2 and a potential difference, V_r, is simultaneously measured between R_1 and R_2. The transfer impedance, $Z = V_r/I_t$, is a function of the dielectric properties of the environment. The probe array can be arranged in an infinite number of ways and a possible configuration is illustrated in the following figure (probe R_1 not visible), where four spheres are mounted at the corners of the vehicle (4). Assuming a square array of side L at a height h above the ground and neglecting the presence of the rover body, it can be shown that the transfer impedance is approximately given by $Z = Z_o\,(0.59 - 2\alpha((1 + x^2)^{-\frac{1}{2}} - (2 + x^2)^{-\frac{1}{2}}))$, where $Z_o = (4\pi j\varepsilon_o L\omega)^{-1}$, $\alpha = (\varepsilon - 1)/(\varepsilon + 1)$ and $x = 2h/L$. The transfer impedance can be rewritten $Z_o \simeq (0.59 - \alpha(0.59 - 0.65\,x^2))$ for $x \ll 1$. The size, geometry and location of the sensors are not critical; in order to minimize the mass, it is proposed to make use of meshed spheres or disks with a diameter of about 10 cm, small compared with the dimensions of the vehicle. The sensors should be mounted as close as possible to the ground (~15 cm) and as far as possible from the vehicle (~30 cm); it is absolutely not required that the array be square. The perturbation introduced by the presence of the rover will be taken into account through a preliminary calibration. The sensors are not rigid and the mounting stems are flexible so that any unforeseen contact with ground protrusions cannot affect their shape nor impede the operation of the vehicle. The working frequency is varied in steps from 100 Hz to 3 MHz; the amplitudes of the transmitted current and received voltage are measured and the difference between the phases of the two signals is evaluated for each frequency step. As a bonus, it is possible to monitor in the passive mode, i.e. without any signal applied to the transmitting dipole, the activity of atmospheric VLF electromagnetic phenomena (frequencies less than 10 kHz), by sending the signal collected by the receiving antenna into a filter bank, or a spectrum analyzer. The quadrupolar probe is a sturdy and versatile instrument with relatively modest requirements (2 W, 2 kg).



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MARS SAMPLING STRATEGY AND AEOLIAN PROCESSES;

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It is critical that the geological context of planetary samples (both *in situ* analyses and return samples) be well known and documented. Apollo experience showed that this goal is often difficult to achieve even for a planet on which surficial processes are relatively restricted. On Mars, the variety of present and past surface processes is much greater than on the Moon and establishing the geological context of samples will be much more difficult. In addition to impact gardening, Mars has been modified by running water, periglacial activity, wind, and other processes, all of which have the potential for profoundly affecting the geological intregity of potential samples.

Aeolian, or wind, processes are ubiquitous on Mars. In the absence of liquid water on the surface, aeolian activity dominates the present surface as documented by frequent dust storms (both local and global), landforms such as dunes, and "variable features"--albedo patterns which change their size, shape, and position with time in response to the wind. Aeolian processes involve the erosion, transportation, and deposition of material by the wind and have the potential for:

- "sorting" some materials by size, density, and composition
- "homogenizing" some materials via dust storms
- altering rock compositions by the formation of desert "varnish"
- forming deposits which range in thickness from a few µm to tens of meters
- eroding rocks through abrasion and deflation

In some cases, these processes have a negative effect on sampling goals; in other cases they may help achieve sampling goals. In all cases, the potential effects of aeolian processes must be taken into account in developing sampling strategies.

Wind sorting. In some cases, wind is an effective agent for separating materials. Depending upon wind strength, fine material is deflated, transported by the wind, and redeposited in other areas. In the process, windblown materials become sorted by size and density. The surface which remains is also altered; large or high-density particles may remain as a lag deposit, contributing to the development of desert "pavement" surfaces.

Homogenization. The fine material carried into the atmosphere via dust clouds has the potential for becoming thoroughly mixed. Estimated to be less than a few microns in diameter, martian dust-cloud material is globally transported.

Thus, dust derived from diverse geological sources may become homogenized in the dust cloud and, as such, may reflect a type of planetary compositional average.

Desert varnish. In many desert regions on Earth, rocks are commonly coated with a veneer of dark material, termed desert varnish. Although its origin is somewhat controversial, one commonly accepted model involves windblown dust which adheres to surfaces and reacts with dew to form a layer which may be a centimeter or more thick. Compositional measurements obtained via remote sensing or through shallow surface sampling thus may represent only the varnish and may be markedly different from the "host" rock. Although desert dew or its equivalent is unlikely on Mars today, a type of martian varnish may form through other processes. For example, laboratory experiments simulating Mars show that under the high winds required to transport material in the low-density martian atmosphere, some particles impact rocks and adhere to the surfaces. Although the amount of water in the martian atmosphere is miniscule, over the long periods of exposure typical for martian surfaces, reactions may occur in which the adhering particles react with the host rock to develop a desert-like varnish.

Sedimentary deposits. Smooth plains deposits are found in many regions of Mars, including the layered terrain of the polar areas, mantling deposits found in some equatorial regions, as intercrater plains deposits, and as crater-filling units. Although the origin of some of these units is generally accepted as aeolian (e.g., the polar layered material), the sources and evolution of some of the smooth plains is highly controversial. For example, mantling material in the Memnonia region has been proposed to be widespread ignimbrite deposits. As such, they could be extremely important sampling sites. Alternatively, these materials could be deposits of windblown dust. Similarly, other smooth plains deposits on Mars have also been suggested as volcanic in origin, yet could also be aeolian.

Erosion and deflation. Erosion of the surface by the wind and deflation of weathered materials in some areas may enhance sampling efforts. Low-albedo surfaces, including those found in the "wake" zones of some craters, may represent eroded and deflated bedrock surfaces and could be high-priority sites for obtaining relatively fresh samples.

In summary, aeolian activity dominates the present surface of Mars and appears to have played an important role in the evolution of its surface. Recognizing the occurrence of windblown deposits and the potential for aeolian processes in modifying the surface must be taken into account in developing sampling strategies.

MARS SAMPLE RETURN: A BIOPHYSICAL COMMENT

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INTRODUCTION

For a sample return mission it is important to consider the following requirements:

1) the selection of optimal landing sites (a ranked list of possible landing locality types could be drawn up using data from Earth-based geological studies).

2) the handling of samples collected so that data can be retrieved after return from Mars (in establishing such procedures the fact that Mars is not like the moon will have to be considered).

3) more data would be extracted from the returned samples than from on-site experiments.

In fulfilling these requirements, preparative studies of the interface between geochemical and biochemical cycles need to be undertaken as part of a biophysical Mars program. This contribution outlines at least part of the work needed.

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PETROLOGIC CONSTRAINTS ON THE PRESSURE, TEMPERATURE, TIME AND COMPOSITION OF THE MATRIAN INTERIOR: SAMPLES AND EXPERIMENTS.

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Petrologic analysis of surface samples has been used to deduce pressure and temperature conditions existing in the crust and upper mantle at specific times in the Earth's history, as well as to estimate the chemical and mineralogical composition of the crust and upper mantle. The same techniques can be applied to samples of the Martian surface to provide P, T, time and composition constraints of the Martian interior. Estimates of P and T conditions existing at a given time would, in turn, provide strong constraints on the thermal evolution of Mars. Knowledge of the chemical and mineralogical composition of the Martian interior is of fundamental importance in assesing the early histroy of the solar system. In this abstract I outline the general petrological approach, describe the kinds of sample required, summarize our current understanding of the Martian interior based on experimental petrology, and outline some of the important experiments needed to allow a full petrologic interpretation of Martian samples. *Xenoliths* in lavas and pyroclastics often contain mineral assemblages which can be used to calculate P and T with high precision using available thermochemical models (1). However, xenoliths are volumetrically rare on the Earth's surface and it is unlikely that they will be found by initial Martian expeditions. The most common surface rocks on Mars are lavas and so these are the samples which will have to be used in a petrologic analysis to deduce pressure, temperature, mineral assemblage and chemical compositions of the interior of Mars. *Primary magmas* are most useful because, by definition, they have not undergone fractionation since leaving their source region. Primary magmas are identified by the atomic ratio of Mg/(Mg+Fe), the mg#. Comparison of the composition of a primary magma with experimentally determined compositions identifies the phase assembalge of the source region which is used to estimate pressure (2). The experimentally determined solidus is then used to estimate temperature. The source region phase assemblage helps constrain the chemical composition. Terrestrial primary magmas are most often found in monogenetic cones and associated flows. These too are uncommon and not all monogenetic cones are formed from primary magmas. It is thus probable that primary magmas will not be sampled in initial expeditions. *Fractionated magmas* almost certainly form the major volcanic features on Mars and so are the most probable type of sample to be obtained. In favorable instances the composition of the primary magma parent of a fractionated magma can be estimated. The strongest constraints are a combination of the observed chemistry with experimentally determined crystallization sequences. If the primary magma composition can be estimated in this way then the technique outlined above can be used. This more convoluted path introduces greater uncertainty in the estimated mantle conditions, but has been used sucessfullly to estimate the P T conditions in the source regions of mid-ocean ridge basalts on Earth (3). Making those estimates required several samples of the same general rock type. The utility of any of the possible sample types is seriously degraded by secondary alteration or weathering. The sample size must be large enough to ensure homogeneity, so it is proportional to grain size.

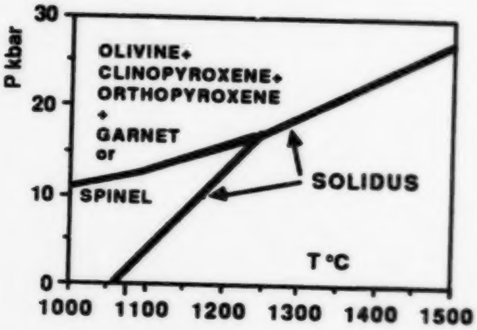

Figure 1. Garnet-spinel transition (7) and solidus (6) for Martian mantle with mg# =78.

Current assesments of the chemical composition of the Martian interior are based on the primary constraints of mean density and moment of inertia, together with experimentally determined mineral densities, and chemical models using either chondritic meteorites (4) or SNC's (5). For the most recent estimates of mantle density based on refined moment of inertia values there is very good consistency between the chemical models. Those models result in significaltely lower mg#'s for Mars compared to the Earth, and slightly higher (Fe+Mg)/Si.

Experiments on volatile (H_2O and CO_2)-free compositions show that the mantle mineral assemblage is olivine + clinopyroxene + orthopyroxene + aluminous phase to depths of >200 Kms (6). The aluminous phase is either spinel or garnet depending on pressure (Fig.1). Experimental determination of the minimum melt composition for a volatile-free Martian mantle ar 23 kbar shows that the liquid is low in Si and Al and high in Fe and Mg with a low mg# (Table 1). These low melting fraction liquids will show REE paterns characteristic of equilibration with garnet only for degrees of melting ≤ 2-5 wt% liquid. Similiar results for minimum melt compositions are not available for the spinel field, but by analogy with terrestrial systems they will have higher Si/(Fe+Mg). As the melting fraction increases, the liquid will show a decrease in mg# and a slight increase in (Mg+Fe)/Si.

Table 1
Minimum Melt Compositions*

Oxide	Mars	Earth
SiO_2	41.	45.
Al_2O_3	12.	12.
FeO	23.	15.
MgO	12.	25.
P(kbar)	23.	35.
Ref.	(6)	(8)

* In equilibrium with garnet, olivine, clinopyroxene and orthopyroxene.

An important consequence of the unusually high Fe and low Si content of Martian primary liquids is a very high melt density. Preliminary experimental results show that pyroxene and olivine float in minimum melt compositions at 23 kbar (13). This phenomenum will have major consequences for phase stratification in the Martian mantle, quite possibly preventing magmas from rising in the garnet stability field. The more silica-rich magmas from the spinel stability field are less dense and presumably could rise to the surface.

Additional experiments will be needed to provide a useful data base for the understanding of Martian samples. Determination of the subsolidus mineralogy is needed for Martian mantle composition in the spinel field and also at pressures equivalent to the core-mantle boundary. Ultra-high pressure systems are now available for subsolidus and melting studies up to 25 GPa, the approximate pressure of the core-mantle boundary (9). There is theoretical (10) and direct (11) evidence that the Martian mantle is at least as rich in volatiles and the Earth's. Dissolution of volatiles such as H_2O and CO_2 at high pressures are known to cause drastic changes in the composition, density and viscosity of primary magmas (12) and so we must evaluate the effects of those volatiles on Martian mantle compositions. Finally, the observation that the most common of the mantle minerals float in some Martian primary magmas points out the necessity of accurate measurements of melt density over as wide a range of pressure as possible.

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SPECULATIONS ON THE IGNEOUS HISTORY OF MARS: INFERENCES FROM THE SNC METEORITES.

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In general, attempts to delineate an a priori sampling strategy for missions to terrestrial planets must be simple. In the case of the Moon, for example, the simplest and most obvious plan -- that to sample both the highly-cratered, high-albedo highlands and less-cratered, low-albedo mare -- has proven very useful. However in the case of Mars, multiple missions and/or roving samplers may prove expensive or infeasible. Thus, we may be limited to collecting samples from a single site, and, consequently, consideration of sampling strategies for a Mars mission is more critical than for the more-accessible Moon.

Based on the orbital and surface photography of the Mars Mariner and Viking missions, four types of martian samples are probably available: (i) basaltic rocks, such as comprise the Tharsis volcanic plateau; (ii) granitic(?) rocks from the heavily-cratered ancient crust; (iii) windblown dust and "loess;" and (iv) sediments and fluvial deposits, formed during the events that produced the martian channels. Here, it will be argued that the samples which will be most informative are a combination of basalts and windblown dust. The logic behind this conclusion is based on three observations. Firstly, evidence from the SNC meteorites argues that basaltic samples will yield information both about the mantle and crust of Mars. Secondly, the global nature of martian windstorms [1] implies that windblown dust can provide a representative sample of the martian crust. Thirdly, dust storms the size of those on Mars should ensure that dust deposits are nearly ubiquitous. Consequently, any sampling venture to collect basalts could also sample dust, and these two dichotomous sample sets should provide constraints on the geological history of Mars.

The latter observations are based on Mariner, Viking and Earth-based imaging and require no explanation. The first observation, based on the chemical and isotopic relations within the SNC suite, will be explored in more detail. Below, it is assumed that the SNC meteorites are martian. The questions that will be addressed are: (i) can the SNC suite be explained within a single petrologic framework? and (ii) do the SNC meteorites give us information about the nature of the martian crust and mantle? The answer to both questions is believed to be yes.

Isotopic systematics of the SNC meteorites. The nakhlites and Chassigny have the simplest isotopic relationships. A variety of isotopic dating methods yield an igneous crystallization age of ~1.3 Æ for these rocks [2]. Within error, Nakhla and Chassigny have the same initial ^{87}Sr/^{86}Sr [3,4]. All the nakhlites and Chassigny have cosmic ray exposure ages of about 10 m.y. [2]. These meteorites thus comprise a group of closely-related igneous rocks which crystallized pene-contemporaneously and then were simultaneously exposed to cosmic radiation.

The shergottites are much more complex, and a variety of ages have been proposed for this group. Igneous crystallization "ages" from whole-rock and internal isochrons range from 1300 to ~150 m.y. [2,5], but, regardless of the exact time of crystallization, the event(s) must have occurred relatively recently (≤ 1.3Æ). In contrast, whole-rock Rb-Sr and Pb-Pb analyses of the shergottites yield "ages" of 4.0-4.6Æ [6]. The simplest explanation for the older whole-rock isochrons is that, at the time of crystallization, there was mixing between two isotopically distinct reservoirs that had been separated for ~4.5Æ. If this interpretation is correct, then all whole-rock ages are suspect and igneous crystallization ages are confined to a period of 360 to 150 m.y.

Presently, the only shergottite ages that recur in all rocks and isotopic systems are 150 - 250 m.y. [2]. Various interpretations have been given to this narrow range of ages, but the preservation of igneous zoning trends and the absence of any evidence of thermal or hydrothermal metamorphism argue that these ages reflect igneous events -- not shock or metamorphic resetting [6]. Below, the crystallization ages of the shergottites will be assumed to be ~180 m.y.

Chemical signatures within the SNC suite. The chemistry of the SNC suite has three major points of interest. (i) Shergotty, Zagami and EETA79001 (hereafter, 79001) are quartz-normative, pyroxene - plagioclase basalts which probably do not represent simple mantle-derived magmas [7]. (ii) The nakhlites, Chassigny, ALHA77005 (hereafter, 77005) and 79001(?) plausibly crystallized from mafic (or ultramafic) magmas -- or from the evolved products of such magmas -- which crystallized olivine and calcic pyroxene [7,8]. Whether 79001 should belong to this group is unclear. Although 79001 is quartz-normative, ultramafic xenoliths in 79001A have the same age and initial $^{87}Sr/^{86}Sr$ as their host [9] and could possibly be "cognate" xenoliths from an earlier, mafic precursor to the 79001A magma. (iii) Using the assumption of a 180 m.y. crystallization age, Shergotty and Zagami have negative $\varepsilon(Nd)_I$ while 79001, 77005 and the Nakhla source region have large, positive $\varepsilon(Nd)_I$ [6]. There is a rough correlation between $\varepsilon(Nd)_I$ and $\varepsilon(Sr)_I$ which is suggestive of mixing between complementary reservoirs that have been separated for long periods of time, as has been suggested for some terrestrial basalts [10]. This same type of relationship between the shergottites and the Nakhla source region can also be seen on a $^{207}Pb/^{204}Pb$ *vs.* $^{206}Pb/^{204}Pb$ diagram [6].

A model, with application to martian sampling. The limited amount of evidence that we currently possess suggests that Mars differentiated into a crust and a depleted mantle very early in its history (4.0 - 4.6 Æ ago). The evidence also suggests that there has been igneous activity on Mars within the last 200 m.y. and that the final products of this activity (shergottites) were produced by extensive interaction of mantle-derived mafic magmas with an ancient sialic crust. Nakhlite and chassignite magmas apparently avoided much of this contamination and remained very mafic [8]. The lack of a precisely defined mixing line for shergottite $\varepsilon(Nd)_I$ *vs.* $\varepsilon(Sr)_I$ does not invalidate the general model, but does prohibit simple, two-component mixing. The crust and/or mantle of Mars is probably isotopically heterogeneous.

This model provides a general construct both for sampling the martian surface and for testing the SNC analog. Sampling should begin in the Tharsis region -- the volcanic province that is least cratered and that should represent the most recent igneous activity. The radiometric ages and oxygen isotopes of rocks from Tharsis should be sufficient to address whether SNC's do come from Mars. If they do, then variations in chemical and isotopic compositions of SNC meteorites and **collected basalts and dusts** should allow evaluation of crustal and mantle signatures.

Caveat emptor. Clearly it is difficult to generalize, on the planetary scale, from a few samples of poorly-known provenance which have had a complex petrogenesis. However, the most chronic SNC problem, that of the radiometric ages of the shergottites, is not necessarily the most acute. For example, if one generalizes from the 77005 data of [5] then the time of maskelynitization of the shergottites was less than 30 m.y. ago. Thus, if the whole-rock ages are viewed with suspicion, the only possible times of igneous crystallization (150 - 360 m.y.) are too similar to greatly affect the above conclusions.

In many ways the 1.3Æ Sm-Nd whole-rock isochron of the shergottites is the most difficult observation to relate to the model presented above. Firstly, in the simplest model, Sm-Nd mixing between a crust and a magma from a depleted mantle should yield an isochron that is ≥ 4.5Æ -- not less. More complex petrogenetic models can alleviate this problem somewhat, but not in any truly satisfying way. Secondly, there still exists the concordance of ages between the shergottite Sm-Nd whole-rock isochron and the internal isochrons of the nakhlites and Chassigny.

For the present, because there is no evidence for an event at 1.3Æ in the shergottites' Pb-Pb systems [11], it seems most prudent to view the 1.3Æ age as coincidental. The difficulty in achieving an age that is less than 4.5Æ can probably be circumvented by postulating a heterogeneous crust (and/or mantle) -- a conclusion already implied by the $\varepsilon(Nd)_I$ *vs.* $\varepsilon(Sr)_I$ discussion. Presently, it seems that dating systems with parents that are very incompatible during silicate partial melting (U-Th-Pb, Rb-Sr) paint a simpler picture of martian evolution than Sm-Nd.

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HELLAS BASIN EJECTA: A PRIME STRATIGRAPHIC MARKER AND SAMPLING TARGET;

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The Hellas Basin and associated ejecta deposits dominate a large portion of the southern highlands of Mars. These deposits have been particularly well-documented at the scale 1:5,000,000 in the Sinus Sabaeus (MC-20), Iapygia (MC-21) and Mare Tyrrhenum (MC-22) quadrangles (1, 2, 3) where they have been mapped as ancient "hilly and cratered material." In MC-22 the ejecta deposit is interpreted to thin from west to east, away from Hellas. In the eastern part of MC-22, the outlines of some large older craters, such as Hershel, can be seen through the thin ejecta cover and some of these buried craters even have enough relief to act as depositional traps for later mostly eolian sediments. Superposed on the ejecta is a population of numerous intermediate-sized to smaller craters which indicates the relatively old age of the ejecta deposit and causes the unit to have rather rough surface topography. Numerous small channels on steeply sloping crater rims and regionally sloping surfaces indicate erosion, transportation and redeposition of substantial amounts of ejecta materials, probably by aqueous fluvial processes. Numerous more recent volcanic constructs and flows also are superposed on the ejecta. In some places these features further contribute to the surface roughness of the unit.

The characteristic surface roughness of the Hellas Basin continuous ejecta cover makes it unlikely that a landing site for a sample return mission will be selected on this unit. However, it is clear that our knowledge of the true extent of the ejecta unit is severely limited by the resolution of the presently available orbital imagery. Higher resolution imagery should make it possible to locate isolated occurrences of the ejecta that are surrounded by or adjacent to smoother later stratigraphic units. These smoother units might be suitable as landing sites that could provide sampling access to the ejecta with only modest mission mobility requirements.

The Hellas Basin ejecta unit is of interest for sample return for several reasons. It is an old unit that can be used as a near-contemporaneous time-stratigraphic marker over a large portion of the planet. Although there is no calibration of martian crater statistics with known accuracy, even the most widely divergent opinions (4, 5) agree that the unit is very old, perhaps 4.0 billion years. Because of the great energy of the event, the ejecta should contain old rocks from the deep martian interior. Furthermore, the ejecta has been exposed in the near-surface environment for a long time which should be reflected in sample mineralogy, oxidation and alteration states. This possibility also is indicated by the observed abundance of small channels of probable fluvial origin that occur on the surface of the ejecta unit which suggest substantial interaction between rocks of this unit and martian volatiles.

The tremendous extent of the Hellas Basin ejecta, its potential use as a practical time-stratigraphic marker, the probability that the unit contains very old rocks from deep within Mars, and that much of the ejecta has been in contact with or altered by water and possibly other volatiles renders the ejecta unit a prime candidate for sampling by an early sample return mission.

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CONTINUING THE BIOLOGICAL EXPLORATION OF MARS; Harold P. Klein, Department of Biology, Santa Clara University, Santa Clara, CA. 95053

Mars has been an object of interest for the better part of this century. To a biologist, Mars assumes special importance because many aspects of the "theory of chemical evolution" for the origin of life can be tested there. The central idea of this theory is that life on a suitable planet arises through a process in which the so-called "biogenic elements" combine to form increasingly more complex molecules under the influence of naturally-occurring energy sources ultimately resulting in the formation of replicating organic molecules. The "biogenic elements" are present on Mars today. Furthermore, the available evidence also strongly suggests that Mars may have had an early history similar to that of the Earth, including a period in which large amounts of liquid water once flowed on its surface and a denser atmosphere and higher global temperatures prevailed. This is important since many lines of evidence indicate that living organisms were already present on the Earth within the first billion years after its formation- at a time when the environment on Mars may have closely resembled that of the Earth.

Our current knowledge of the state of chemical evolution on Mars can best be described as paradoxical. Most of what we have learned has come from experiments performed on the Viking landers. The combination of planned investigations covered a broad range of techniques to detect signs of chemical evolution. The most surprising data from all of these was the absence of any detectable quantities of organic compounds at the two landing sites . On the other hand, the Viking experiments did indicate that the Martian surface samples contained unidentified strong oxidant(s) that could account for their absence. The identity and topographical distribution of this material on Mars are, at present, unknown. In the samples that were tested, its apparent concentration varied over a ten-fold range and was inversely correlated with the water content of the samples. If this correlation is correct, it would be important to identify sites on Mars where the oxidant(s) is presumably absent (e.g., in the "wet" polar regions) and then to probe there for the presence of organics. With regard to the possibility of finding replicating systems on Mars, no signs suggestive of a living biota were seen by the imaging team after analyzing hundreds of lander images. Nor was there unequivocal evidence for metabolic activity in any of the many samples that were tested in the Viking biology instrument. It is true that some of the data obtained in the metabolic experiments are consistent with a biological interpretation, but this is the case only when viewed without considering all of the Viking results and the ground-based studies that were carried out in efforts to understand the Viking data.

In contemplating future possible missions to Mars, we are left with almost complete ignorance on questions of fundamental importance to biology. What *was* the course of chemical evolution on Mars? Did organics survive on Mars long enough to be built into molecules of biological significance? Did such a process ever result in the formation of *replicating systems* ? If this is so, was the resulting biota able to adapt to changing conditions as that planet gradually lost most of its atmosphere, dried out, and became "inhospitable"? That is, are there any specialized ecological "niches" on Mars where indigenous organisms may still be present? The Soviets, in describing their plans for the future exploration of Mars , appear to have placed a high priority on looking for such biological "oases" and on the subsequent search for living organisms at these sites. Recognizing the heterogeneity in the topography of the planet, and the implied potential for heterogeneous micro-environments, extrapolations from the Viking results to the entire globe can not be made with complete confidence. One need only recall that some micro-organisms on Earth have "retreated" into the insides of rocks in

Antarctica, where they have established an environment sufficiently different from the ambient environment to allow them to sustain their growth, or that others have adapted to a non-photosynthetic existence in or near submarine hot-springs that vent from the ocean floor at extremely high temperatures. One question, then, is whether conditions *anywhere* on Mars can still support the growth of organisms- if a biota ever existed there. Another scenario, however, seems more plausible: that chemical evolution on Mars may well have produced living organisms under more favorable conditions, but that these ancient organisms were unable to adapt to worsening conditions and became extinct. Thus, while Mars may now be a "dead" planet, it may still retain evidence for the earlier presence of organisms. This evidence may exist- as it does for the early Earth- in the form of fossilized specimens, preserved (or modified) organic materials derived from the ancient organisms, or carbon, nitrogen, or sulfur- containing materials that show isotopic ratios characteristic of biological processes. In this scenario, of critical importance is how much time might have been available for biological development and diversification. If suitable conditions were maintained for even of the order of a billion years on Mars, its biota could have been widely dispersed. On the Earth, microbial ecosystems were already well-established and well-distributed within this time period. Vestiges of an early biologic era on Mars will require considerable further preliminary exploration of the planet in order to identify potential sites for biol;ogical investigation. Much of the surface of Mars appears to be of ancient origins, going back to well within the first billion years of Mars' evolution. Sub-surface samples from such areas may be accessible and would be useful for study. Other features on Mars indicate that numerous channels were cut in its surface by flowing water, and extensive networks of valleys exist that also appear to be of ancient derivation. Moreover, some of the canyons within the large equatorial *Valles Marineris* canyon sytem on Mars appear to be made up of layered sedimentary material, suggesting deposition in standing bodies of water. Evidence for early biological processes may yet exist in these regions.

It will probably require many missions to Mars to adequately test our current theories about chemical evolution. Ultimately, we may find verification for these ideas on Mars. Conversely, we may find no persuasive evidence to support the theory. In this case, we may learn- or deduce- why the process was prevented or aborted on Mars, and we would then be left with an essentially unverified theory. It is also possible that, in the end, we will have found no evidence to support this theory- without identifying any specific contravening factors. Such a conclusion would have a value unto itself: it would call into question the basic premises upon which the theory of chemical evolution rests.

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SAMPLING MARS: ANALYTICAL REQUIREMENTS AND WORK TO DO IN ADVANCE.

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Introduction Sending a mission to Mars to collect samples and return them to the Earth for analysis is without doubt one of the most exciting and important tasks for planetary science in the near future. Many scientifically extremely important questions are associated with the knowledge of the composition and structure of Martian samples. Amongst the most exciting questions is the clarification of the SNC problem - to prove or disprove a possible Martian origin of these meteorites. Since SNC meteorites have been used to infer the chemistry of the planet Mars, and its evolution (including the accretion history), it would be important to know if the whole story is true. But before addressing possible scientific results, we have to deal with the analytical requirements, and with possible pre-return work.

Sample size considerations. It is unlikely to expect that a possible Mars sample return mission will bring back anything close to the amount returned by the Apollo missions. It will be more like the amount returned by the Luna missions, or at least in that order of a magnitude. This requires very careful sample selection, and very precise analytical techniques. These techniques should be able to use minimal sample sizes and on the other hand optimize the scientific output. The possibility to work with extremely small samples should not obstruct another problem: possible sampling errors. As we know from terrestrial geochemical studies, sampling procedures are quite complicated and elaborate to ensure avoiding sampling errors. The significance of analysing a milligram or submilligram sized sample and putting that in relationship with the genesis of whole planetary crusts has to be viewed with care. This leaves us with a dilemma: one one hand, we would like to minimize the sample size as far as possible in order to have the possibility of returning as many different samples as possible, and on the other hand we have to take a sample large enough to be representative. Whole rock samples are very useful, but should not exceed the 20-50 g range, except in cases of extreme inhomogeneity, because for larger samples the information tends to become redundant. Soil samples should be in the 2-10 g range, permitting the splitting of the returned samples for studies in different laboratories with variety of techniques. If we assume that the average analyst (with an average analytical technique) is able to work with some 10 milligrams of a soil sample, then about 100 different studies can be made per sample and still leave enough for back-up and future work, which should be an essential requirement (like it is for lunar rocks). Whole-rock studies will be more material-consuming, because of the integrated approach. Studies of single minerals are highly desirable. In addition, we have the problem that several analytical techniques need more than 10 mg of sample material, at least if considering the state-of-the-art today. This leads to the second topic.

Pre-return improvement of analytical techniques. This may be seen in analogy to the developments associated with the study of lunar rocks. One example could be the improvement in the electron microprobe analysis technique, which would not have seen such fast and thorough improvement without lunar science. We can expect something similar to happen if Martian samples

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are to be returned to Earth. This also leads to an important spin-off of analytical technology, a consideration which is, in view of recent science policy decisions, rather useful.

Amongst the techniques which would require improvements are the following: analysis of trace elements and isotopes in single minerals. The investigation of the chemical and isotopic properties of single minerals within a mineral (or rock-) assemblage was proven to be of great geochemical significance. Describing the history of a rock from formation to collection should be the ultimate goal, and very often the minerals contained in a rock have had different histories. The extraction and analysis of minerals pertinent to age determinations has to be improved considerably. The ion probe dating techniques in use for zircon dating have shown great potential, but do not yet seem to be a routine analytical tool due to too many uncertainties. This very useful technique will have to be improved before being used on precious Martian samples. The same will apply for radiochemical studies of certain trace elements. Amongst the more interesting elements in a geochemical sense are volatile trace elements. Due to analytical problems, and also due to interpretative problems, these elements have not been used according to their geochemical importance. Examples would be the group of the halogens, or elements like Li, B, As, Sb, Se, Cd, Ag, Te, or In. The analytical requirement would be to improve the techniques associated with the the analysis of these elements (like radiochemical neutron activation analysis) to gain higher sensitivity, better reproducibility, and precision. Also, these elements are most vulnerable to post-collection alterations of the samples, such as sterilization procedures. Without going into details we can assume that most of the information contained in volatile elements (like the chemistry of sedimentary processes, or volcanic eruptive processes) will be destroyed if the samples are subjected to anything which comes close to a classical sterilization procedure. We have to consider not only the information contained in the distribution of volatile elements, but also the information contained in the structure of highly volatile compounds, like ices (which may be present in Martian surface samples). Also some inorganic compounds (carbonates, hydrated minerals) are extremely vulnerable to sample alterations, but would contain very important information. Thus all post-collection sample alteration procedures should be either avoided or carefully monitored and kept to minimum.

Another requirement would be the development of improved sample preparation and handling techniques, which do not exist in the necessary extent for such fragile and precious samples. Analog studies (e.g. with Antarctic meteorites) could be very useful. Further points on the wish-list would be the xploration of new geochemically significant isotope systems, like osmium isotopes, or platinum isotopes. These procedures still require rather large sample sizes, and isolation, extraction, and detection systems will have to be improved for Martian samples.

Conclusions. This short list is merely a starting point, and should serve only for stimulating pre-return science. With a project as complex and possibly scientifically rewarding as a Mars sample return mission, considerable thoughts and efforts have to go in pre-return scientific requirements. The improvement of analytical techniques and facilities is of crucial importance.

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SOME LESSONS FROM APOLLO FOR A SAMPLING STRATEGY ON MARS FOR UNDERSTANDING THE ORIGIN OF THE ANCIENT IGNEOUS CRUST AND THE COMPOSITION OF THE MANTLE. Randy L. Korotev and Larry A. Haskin, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130.

Proper site selection for sample collection is crucial to determining the nature and time scales of major events on Mars. From a comparative planetological standpoint, an important consideration in sampling Mars is to obtain samples of igneous rock from which, through the analysis of lithophile elements and their radiogenic isotopes, we can infer the compositional nature of the Martian crust, the processes that led to its formation, and the timing of its major evolutionary events. Analysis and interpretation of lunar samples acquired by the Apollo lunar missions provides valuable experience on the effects of site selection for this purpose. Lunar samples are our main source of information on the nature and history of formation of the Moon's crust.

"Typical" material. Igneous evolution of Mars produced three general types of crustal terrain: the ancient, cratered southern hemisphere, the younger northern hemisphere, and the still younger major plateaus with their stratovolcanoes. We need samples of igneous rock unambiguously characteristic of all three terrains. A serious problem in the interpretation of data for lunar samples is that only a small fraction of the samples come from prevalent types of lunar crust, as inferred from the results of various remote sensing techniques. Apollos 11 and 12 landed in mare basins at sites selected (sensibly) for reasons of safety, but selected without benefit of prior spectral mapping to determine representativity. Of the nine Apollo plus Luna sampling missions, seven were to maria or to mare-highlands interfaces; none was to a "typical" highlands site. Mare materials are important as indicators of time scale and as probes of mantle composition. In order to characterize the early lunar crust satisfactorily, we need samples from at least a few broadly typical regions of the highlands. The Fra Mauro highlands region (Apollo 14) was chosen as an interesting highlands area, but turned out to be geochemically very atypical. The Apollo 14 samples are very important, but it is still not clear how they relate to other parts of the lunar highlands. Data from the Mars Observer will help us discover prior to sampling whether a site is geochemically "typical" or not. Apollos 15 and 17 landed at interfaces between maria and the highlands and probably provided samples typical of neither. Many of the rocks and all of the soils from these two sites are mixtures of mare and nonmare material, which complicates our attempts to characterize the highland components [1,2]. Only Apollo 16 landed in a region remote from mare basins. Even samples collected there turned out not to be geochemically "typical;" Apollo 16 soils have concentrations of incompatible trace elements 2-3 times higher than the mean values for the highlands surface. The lunar meteorites discovered in Antarctica and the soil from Luna 20 more closely resemble the mean surface crust in composition than do any of the Apollo soils [3,4,5].

The temptation is great to sample areas expected to provide a diversity of sample types or that are regionally "interesting" based on photogeologic data. Nevertheless, it is imperative to our understanding of major evolutionary features of a planet that we obtain samples that unambiguously represent areas that, even if mundane, are typical. Sampling only at sites with interfaces between types of major terrain may not accomplish this.

Large *vs.* small samples. Primarily as a result of our experience with lunar samples, we can extract much information from small samples. In fact, with most types of sophisticated instrumentation for chemical and isotopic analysis of geologic materials, samples exceeding 0.1-1.0 g in mass cannot be analyzed directly but must be subsampled. This is so even for terrestrial samples, where the supply is often limitless. A 100 mg sample can easily be analyzed for concentrations of 30-40 chemical elements [e.g., 5]. Of course, 100 mg is too little to represent a hand specimen or an outcrop. For terrestrial rocks, kilogram-size hand samples are pulverized to assure that a subsample represents the hand sample, at least.

Although 49% of the mass of lunar material collected on the last three Apollo missions was rocks exceeding 1 kg in mass, none of these rocks has been (or should be) pulverized in its entirety to produce a representative subsample. Instead, several small chips are analyzed, providing information of the extent of heterogeneity as well as yielding an average that is more nearly representative than analysis of a single chip of equivalent mass. There is no compelling advantage to petrology, geochemistry, and geochronology in acquiring samples many times (e.g., 100+) larger than the largest subsample that can be analyzed in a single determination. A thousand 1 g pebbles can provide far more information than a single 1 kg rock because the former provide information on diversity totally lacking in the latter. A single 1 g pebble may not be representative of an important rock type; however, a single 1 kg rock may not either. Most of the problem of representativeness of small samples can be offset by collecting a large number of such samples. Thus, we suggest that for the types of studies discussed here, most samples need not exceed a few grams in mass.

Cores. At the expense of much time and effort, the Apollo astronauts collected 21 cores in 52 sections totalling about 15 meters in length, containing about 20 kg of regolith, and constituting about 5% of the mass of returned samples. The Apollo cores have been interesting; perhaps their most useful information relates to depth of gardening and how the lunar surface has interacted with the space environment, e.g., the effects of solar wind irradiation. However, the cores have not provided the kind of stratigraphic information that we might desire. In part, this problem is characteristic of the Moon and the chaotic process of lunar regolith formation. However, in large part the problem is characteristic of the coring process itself - only a small amount of useful stratigraphic information can be obtained from a single one-dimensional sample.

It is important to obtain samples from beneath the immediate surface of a planet, but coring is not necessarily the most efficient way to obtain them. Trenching, sampling of crater ejecta, or even blasting some holes can provide deep samples more easily. An effective coring device and the problem of transport and storage of cores complicate a sample acquisition mission. Thus, a coring device should not be used for collecting routine samples. Cores preserve stratigraphy; they should be obtained only when a sample containing an intact profile is specifically required to answer some scientific question. Even then, a core does not guarantee a useful sample if it is too short to include all of the feature of interest.

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ORGANIC AND INORGANIC GEOCHEMISTRY OF SAMPLES RETURNED FROM MARS

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BACKGROUND

Viking 1 and Viking 2 performed three biology experiments and one organic molecular analysis experiment at only two sites on Mars. Interpretation of the results from these experiments and simulations in laboratories on the earth have not satisfactorily answered questions regarding past or extant biological processes. In fact, arguments may be constructed that lead to opposite conclusions concerning present day biology based on the results of the Labelled Release and organic molecular analysis experiments. With respect to the detection of signatures of ancient Martian biological processes, the landing sites and the type of experiment may not have been the most suitable ones. The inorganic chemical cómposition of Martian materials was also determined using x-ray fluorescence spectrometry by the two landers. Samples that were analyzed by the landers were essentially near-surface samples, at most from about 10-20 cm below the surface. Without a knowledge of the mineralogy and a better understanding of the effects of Martian weathering it is difficult to convincingly explain the biology, organic and inorganic chemical data without resorting to speculation. Fortunately, future missions to Mars can benefit from a decade of data analysis and the development of new models for the evolution of the Martian atmosphere, climate and crust.

SAMPLING

Although a tremendous amount of knowledge can be obtained by in-situ experiments on Mars, greater benefits will be realized with sample return missions from the perspective of exobiology. Ideally, an astronaut-driven rover or an intelligent rover would contain a complex of instruments capable of performing in-situ experiments that can serve several scientific disciplines and would have the capability of collecting surface and 1-2 meter core samples. Since the question of extant biology is yet to be totally resolved, an improved life detection experiment package is an essential part of the first missions. This is important whether the focus of such missions is to be the search for present day Martian life or not as positive findings would have a major impact on quarantine issues.

Organic geochemistry has evolved to a mature state in the last few decades with the development of techniques that can detect ppb and sub-ppb levels of individual organic compounds. Models of the fate of the bulk of biological organic matter in the recent sedimentary environment and interpretations of the record of the earth's earliest biosphere have been developed to a sophisticated level. This knowledge can be applied to understand the chemistry of any carbon compounds present in samples from Mars. We propose an analytical scheme similar to those utilized for the analyses of lunar samples and carbonaceous chondrites. Total carbon and total organic carbon analyses and pyrolysis are rapid means to determine whether further studies are warranted. An automated elemental analyzer on a roving vehicle would facilitate organic geochemical sample selection and would also be able to detect carbonates. Aqueous and organic solvent extracts can be screened for amino acids, hydrocarbons and other soluble molecules by a variety of techniques. Insoluble organic matter can be characterized to complement the information obtained from the soluble phases. If the chemistry of Martian materials is indeed exotic, analytical schemes will have to be altered suitably.

In the post-Viking era with Mars appearing to be a planet which possibly had an abundance of liquid water on the surface, places such as the Valles Marineris layered deposits may be ideal locations for organic geochemical sampling. These Martian 'sediments' may contain remnants of any past biological material. If the deposits are analogous to earth lake deposits, they may contain layers rich in organic matter assuming that the same modes of deposition and preservation of organic matter apply. Spectral imaging capability on a rover would enhance the chances of selecting appropriate samples for geochemical studies. The low abundance of liquid water currently on Mars limits the type of localities to sample for evidence of present biology to those such as in the polar regions. One possibility is to search within Martian rocks. An analog on the earth may be the endolithic organisms reported from desert environments. Such organisms may also leave distinctive weathering patterns on the surfaces of rocks.

The Viking biology experiments showed that the surface material on Mars can respond in a manner that mimics biological processes. Earth-based simulations showed that a number of inorganic materials could have been responsible indicating a complicated surface inorganic geochemistry. To support the organic analyses and interpretation, basic inorganic geochemical and mineralogical data will be required. In addition, Martian diagenetic processes have to be understood in the context of both the organic and inorganic components. Toward these goals we propose to characterize Martian samples using a variety of x-ray, microbeam, activation and spectroscopic techniques. The chemistry and mineralogy of clays and hydrous phases in particular is of interest as they may reveal the nature of the paleoclimate of Mars. The nature of carbonates and sulfates is also of interest as they might contain clues regarding volatile evolution.

SCIENTIFIC QUESTIONS TO BE ANSWERED BY SAMPLE RETURN

The combined results of in-situ experiments and investigations with returned Martian material should be able to answer the questions regarding present or past biology and organic chemical processes. If Mars and the earth accreted with nearly equal complements of volatiles and early tectonic and atmospheric processes were similar, it is reasonable to predict that organic chemical evolution led to the emergeance of life. If ultimately, it is discovered that Mars does not and never did possess a biosphere, it would be crucial to understand why this is so. Such an understanding will have a profound impact not only on theories of the origin and evolution of life but also on theories of planetary evolution.

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THE STRUCTURE OF THE MARTIAN CRYOLITHOSPHERE UPPER LEVELS;

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Structural inhomogeneities of the Martian cryolithosphere upper levels were studied by crater method proposed before [1]. On the basis of analysis of 127 photomaps of 1:2 million scale morphological and morphometrical parameters of all the fresh craters larger than 1 km in diameter with fluidized ejecta (9089 craters with D = 1 to 60 km) and without it (1463 craters with D = 1 to 10 km) were investigated. Using the parameters of the craters, the roof depths of ice-bearing rocks were estimated and the data on the ice relative constant in the excavated permafrost layer were obtained. These data were used for the constructing of maps of the boundary depth (minimum and mean) between ice-free nearsurface layer and ice-bearing rocks. A series of maps of the relative ice content for individual permafrost horizons (in 100 meters down to 1 km) was constucted, too. One can deduce from the obtained maps that the zone of the dryest nearsurface rocks on Mars is in the latitudinal belt ±30° where maximum floor depths of the ice-bearing rocks vary from 300 to more than 400 m respectively.

At the latitude 30° the roof depths rise up to 200 m and at the latitude 50° up to 50 to 100 m. As a rule, the maximum roof depths in ±30° lat. belt are localized to the most elevated areas (*e.g.* Syria Planum, Noctis Labyrinthus, Elysium Planum) or to the eldest and elevated areas of the cratered terrain within the southern highlands.

The axis of the zone with the maximum roof depths is not at the equator but displaced to 10 to 15° S.

It was found that the thickness of ice-free rocks in the Southern hemisphere is larger that in the Northern one (by 20% and 38% at 15° S and 60° S lat. respectively). The tendency of similarity of latitudinal zonality observed both on the maps of the minimal and mean roof depths may be considered as an indicator of the structural stability of upper horizons of the Martian cryolithosphere down to the depth of 300 to 400 m. The areas of minimal ice content in the nearsurface layers coincide with the zone of the maximum thickness of ice-free rocks. The ice relative content in Martian rocks becomes systematically higher from 30° lat. to the polars. The same tendency is observed in depth.

The data obtained may be useful for the selecting of landing sites for Mars samples return and other missions.

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THE LIFE ON MARS DILEMMA AND THE SAMPLE RETURN MISSION

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It has now been established (1-10) that: 1. the amount of water on Mars far exceeds initial estimates with liquid water detected within meters of the Mars surface, 2. for at least a billion years large quantities of water flowed on Mars, 3. Mars environmental conditions then were such that life might have developed as it did under similar conditions on Earth, and 4. a wide variety of life forms has been found in the most Mars-like environments on Earth. There is an emerging consensus from the NASA-oriented science community concerning the likelihood that life developed on early Mars. Many scientists, including some of the authors just cited, now propose to make the search for fossils an important part of the Mars Sample Return Mission. However, no one of them mentions the possibility of encountering living organisms. These scientists hypothesize that a catastrophic loss of much of the atmosphere on Mars with consequent cooling and loss of liquid water ended the red planet's experiment with life. They believe the changes exceeded life's ability to adapt, but that such events on Earth, while also drastic, did not. No basis for such a fine distinction currently exists. Indeed, scientific developments trend contrariwise. Life has been found within rocks, within permafrost, and on the dark floors of permanently ice-covered lakes in the Antarctic. Heretofore unknown life forms have been reported in other extreme environments thought uninhabitable. That extant terrestrial bionts many possess, if not in a single organism, all the characteristics necessary for survival on present-day Mars cautions against accepting this arbitrarily imposed limit on evolution with its far-reaching consequences. The dilemma thus created, that life on Earth evolved to survive, but that life on Mars did not argues against a long sought General Theory of Biology.

Furthermore, the Viking Mission legacy exacerbates the dilemma. None of the efforts made by the numerous investigators attempting to explain away the positive findings of the Viking Labeled Release (LR) life detection experiment on Mars has proven scientifically acceptable (11). The primary Viking Mission objective, to determine whether life exists on Mars, remains unresolved. The LR Mars data more than satisfied the pre-launch criteria (12) for a positive finding (13). However, the Viking gas chromatograph mass spectrometer (GCMS) reported (14) no organics in the Mars "soil". This finding was generally accepted by the scientific community as a bar to life on Mars. Later, however, it was revealed (15) that an Antarctic soil gave a positive LR response while the GCMS failed to detect any organic matter in the soil which, by wet chemical methods, was found to contain 0.3 percent organic carbon. These results make it possible to accomodate the Mars LR and GCMS data with the presence of living organisms.

Specific criteria (10) have now been proposed to detect fossils on Mars through imaging. A study of Viking Lander images (16) made to seek visual evidence to confirm the LR data, found colored patterns on rocks satisfing these criteria. Furthermore, lapse-time studies of these images over one and two-year periods indicate possible changes in the patterns.

The NASA Mars Sample Return Mission would be vitally affected by the presence of life on Mars. However, no experiments are presently planned to seek living organisms in the Mars "soil" or to protect humans exposed. The extensive studies (17, for example) of the problems of viable sample integrity and human safety have been set aside on the unwarranted assumption that Viking had demonstrated the sterility of Mars.

At a recent satellite workshop (18), in which US and USSR scientists compared objectives for exploring Mars, polarized views evolved. The US scientists discussed their plans to look only for fossil evidence of extinct life on Mars. The USSR scientists countered vigorously that they will look for living organisms on Mars.

A major objective of the Mars Sample Return Mission should be the resolution of the life problem. A method for doing this is proposed. It follows the time-tested scientific axiom of elaborating on productive investigations. Even if the active agent producing the LR response on Mars is nonbiological, the reactivity of the Mars surface material is of extraordinary interest. It's elucidation should be of high priority. The new Mars lander, therefore, should seek to verify the LR experiment, and then expand the technology to explain the reaction. A simple way that might determine whether the reaction is one of living organisms would be to supply the LR nutrients, including the L- and D-isomers, separately. A response from only isomer but not its enantiomer would essentially prove the presence of life. If life is found, important biochemical information could be obtained. Atmospheric composition, temperature, pH, water content and the like could be controlled and measured for this purpose.

The sample size required for all phases of this study would be aliquots of one cc for a total not exceeding 100 cc. A return to the Viking landing sites might be desirable for replication. However, should the response be attributable to living organisms, they are probably pervasive on Mars as on Earth and sites might be selected to accommodate other scientific objectives as well. In addition to testing surface samples, as was the case with Viking, attempts should be made to obtain deep-hole samples from environments possibly similar to those unexpectedly found to support life in the Antarctic.

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VOLATILE/MOBILE TRACE ELEMENTS IN METEORITIC, NON-LUNAR BASALTS: GUIDES TO MARTIAN SAMPLE CONTENTS; M. E. Lipschutz and R. L. Paul, Dept. of Chemistry, Purdue University, W. Lafayette, IN 47907 USA.

A variety of genetic processes on or in extraterrestrial objects can be examined by study of volatile/mobile trace elements [1,2]. Doubtless, considerable efforts will be expended on determining these elements in returned Martian samples. The purpose of this paper is to estimate levels of such elements expected to be present in returned Martian samples.

Some ideas about Martian genesis have already been advanced from volatile/mobile element contents in SNC meteorites [3-6], assuming that Mars was their parent body. Even if Mars and the SNC meteorite parent body are identical, compositional ranges for returned Martian samples should exceed those of SNC meteorites (Table 1). In general, ranges for 12 volatile/mobile elements (and refractory U, Co and Au) in the only other non-lunar, meteoritic basalts, the HED meteorites (howardites, eucrites, diogenites), are similar to those of shergottites. Ranges for H and D meteorites encompass those for other achondrites. Elements with substantial lithophile character (Ga, U, Rb and Cs) are generally most abundant in shergottites. Data for Chassigny (ALH A77005) and nakhlites fall within or are lower than ranges for shergottites.

We expect, therefore, that Martian samples returned from locations other than Polar regions will have indigenous volatile/mobile element contents within howardite-diogenite ranges. Elements with strong lithophile tendences - like Ga, U, Rb, Cs - may be more abundant, as they are in many lunar samples (e.g. [7]). Most of these elements should be at ppb levels except for Co, Ga, Zn and Rb, which should lie at ppm levels. If Martian volcanism was accompanied by fumarolic emanations, it should be reflected in occasional huge enrichments of mobile trace elements, as in lunar meteorite Y 791197 [8]. Samples from Martian Polar regions may also contain large amounts of such elements. It is conceivable that because of Mars' proximity to the Asteroid Belt, a meteoritic dust component may be even more prominant in Martian than in lunar samples, where it can exceed 2% (e.g. [7]).

During collection and transport Earthward, samples must be contained under conditions appropriate to ppb concentrations. Materials must be used that will not cause contamination such as occurred during the Apollo program, where In from seals contaminated many samples.

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Table 1

Element	Eucrites[*]	Howardites, Diogenites[*]	Shergottites[¶]	Nakhlites[†]	Chassigny[§]
Co[ξ]	1.3-11(37)	7.4-130(17)	30-45 (8)	--	--
Au	0.028-11(36)	0.008-5.2(17)	0.81-16 (10)	0.90	0.56
Sb	0.33-9.2(20)	0.40-42 (10)	1.7-27 (7)	19	0.87
Ga[ξ]	1.1-2.0(36)	0.30-2.7(17)	13-18 (8)	--	--
Se	25-6000(36)	16-7900(17)	290-470(10)	50-64 (2)	37
Te	0.2-20(29)	0.2-59 (16)	1.0-19 (8)	--	50
Bi	0.13-44(30)	0.25-16 (16)	0.47-5.1(9)	5-54 (2)	0.37
Ag	0.26-72(36)	0.14-100(17)	6.3-110(9)	--	2.6
In	0.02-19(37)	0.02-22 (16)	22-68 (9)	15-20 (2)	3.9
Tl	0.04-49(33)	0.07-16 (17)	0.15-14(9)	3.8-6.8(2)	3.7
Zn[ξ]	0.60-7.7(37)	0.08-83 (17)	62-83 (10)	55-72 (2)	69
Cd	0.34-52(35)	0.23-110(16)	13-340(8)	98-110(2)	14
U	8.6-270(33)	0.25-100(16)	55-170(7)	44-65 (2)	15
Rb[ξ]	0.032-0.70(35)	0.004-0.54(17)	1.0-7.3(8)	--	--
Cs	0.88-43(35)	0.10-23 (17)	75-530(10)	350(2)	37

[ξ] Concentrations in ppm: all others are ppb. Where $\geq$ 1 analysis is available, the number of analyses, not samples, is listed in parentheses.

[*] Data from this laboratory.

[†] Nakhla and Lafayette data [6].

[¶] Shergotty, Zagami and EET A79001 data [4-6].

[§] ALH A77005 data [3] are generally similar except for Se (150 ppb), In (11 ppb) and Te (0.5 ppb).

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VALLES MARINERIS, MARS: AN OPTIMUM SCIENCE-SAMPLE SITE;

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The Valles Marineris troughs offer a unique sampling opportunity because they expose a thickness of upper crustal rocks as great as 7 km. Also, because of their long and varied history, the troughs give insights into a number of processes that are critical to deciphering the history of Mars.

Ideal sample sites on Mars would yield information on rocks in close proximity having a range of ages and compositions. The Valles Marineris fulfill these requirements. Very old units of Noachian age (1) are exposed in the lower walls that would give us data on compositions and ages of rocks that are deep below the surface at most other places. The most commonly accepted hypothesis is that these rocks are lunar highlands-type breccia (2). The landslides of the Valles Marineris, also, furnish excellent sites to sample these ancient rocks, because the slides fell from trough walls and thus incorporated wall rock. Additionally, most landslide materials contain some cap rock of the plateau, thus offering an opportunity to sample material of intermediate age (Early Hesperian) (1). The cap rock is commonly interpreted as flood basalts (3), but other compositions cannot be excluded. Younger intermediate-age rocks (Late Hesperian) (1) form part of the layered interior deposits. Their origin is uncertain; they have been considered to be volcanic flows, fluvial deposits (4) or wind drifts trapped in ice-covered lakes (5). Samples of these rocks would illuminate an important segment of Martian mid-history and shed light not only on the composition of these materials but also on the processes that operated at that time.

A second suite of interior deposits occurs on the Valles Marineris floors, resting unconformably on all other units and reaching thicknesses of as much as 3,000 m in western Candor Chasma (6). These rocks are young, of Late Amazonian age, and are most likely of volcanic origin. They are locally composed of very dark materials that are easily reworked by the wind and may have come from young volcanic vents (7). Elsewhere these deposits are of varied albedo and rugged, and they may be composed of volcanic rock of unknown composition. Sampling these rocks and obtaining their precise compositions and ages would be an important contribution to unraveling the thermal evolution of Mars.

Samples from the Valles Marineris would also give insights into a number of Martian processes. The effects of tectonism could be assessed by sampling materials on both sides of young faults that cut the trough floors. Mass-wasting processes resulted in talus slopes and landslides. Whether the landslides were wet or dry is not entirely resolved; this question could be addressed by sampling the matrix of landslide deposits. Furthermore, a large channel appears to have emerged from one of the slides and caused a catastrophic flood (8); sampling of the channel-floor material might confirm this origin. The composition of the channel material may also establish whether ice was involved in the flooding. Water or ice in the channel must have come from the trough walls, and the discovery that either was present would confirm the existence of the hypothetical ground-ice reservoir on Mars.

Wind deposits are abundant on the channel floors. Dark barchan dunes consist of reworked dark material that appears to have come from volcanic vents in the troughs; samples of this material would give compositions and ages, and thus they might confirm the existence of such vents. Establishing grain sizes of the dune material would also shed light on the mechanism of emplacement and, by analogy, on the origin of many similar dunes elsewhere on Mars, particularly those trapped inside craters. Light-colored, reddish dust from atmospheric fallout is also abundant in the troughs and might be sampled to obtain its composition, thus resolving the controversy of whether dust-storm material is composed of smectite clay (9) or palagonite (10).

Overall, the Valles Marineris offer an opportunity to sample rocks that reflect various ages and compositions, giving insight into important processes on Mars. Most of the samples would be located within reasonable proximity and could be easily reached by rovers or balloons. Although landing a spacecraft on the floor of the Valles Marineris may be too dangerous for the first sample-return mission to Mars, the scientific rewards would be so great that such a landing should be considered for later flights.

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EXOBIOLOGY AND THE SEARCH FOR BIOLOGICAL SIGNATURES ON MARS;

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In preparation for a Mars Rover/Sample return mission we must identify the mission goals and objectives. One of the most important objectives must address exobiology and the question of the possibility of the origin and evolution of life on Mars. In particular, we must define key signatures or bio-markers of a possible extinct Martian biota. To that end we must also identify geographic locations (sites) that are likely to contain traces of past life.

The similarity of the early environments of Earth and Mars, and the biological evolution that we know occurred on early Earth, provide the motivation to seriously consider the possibility of a primordial Martian biosphere. Four billion years ago the surface of Mars could have been conducive to the origin of life.

Terrestrial biological systems are dependent upon the presence of liquid water. Consequently, we must narrow our search for traces of an extinct biota to areas that once were overlain with liquid water (*e.g.*, Valles Marineris). How do we detect traces of this possible extinct life? Initially this search should be based upon, and make use of, the techniques developed in understanding Earth's earliest biological evolution (1). These techniques include identifying key chemical, isotopic, and morphological signatures of life that can be determined on Mars and that can act as key indicators, or signatures, of extinct life. Because the histories of Earth and Mars differ, and because our understanding of the history of Mars has many uncertainties, no single technique will adequately determine if a Martian biota ever existed.

Understanding the geochemical cycling of the biogenic elements (C, H, N, O, P, S) and their compounds (*e.g.* CO_2, H_2O, NO_x) on early Mars, as recorded in the Martian sediment, would provide a useful tool in understanding biological evolution. Isotopic signatures are used to understand early Earth and to analyse the interaction between biological and abiological chemical cycles (2,3). Tracking isotopic changes through the Earth's fossil record seems to be correlated to major changes in the atmosphere and biogeochemical cycling. Banin and Navrot (4) suggested that fixed nitrogen and organic carbon are key elements that are enriched through biological processes above their natural geochemical abundances. Therefore, they may be indicators of biological activity in possible Martian sediment.

We have begun defining sites and experiments in support of a Mars rover sample return mission. Although early Mars and early Earth were very similar there were some differences. One of the most crucial of these was the low pN_2. Nitrogen is an essential element of biological systems. However, N_2 is unusable to life as we know it. It must be transformed into biologically available forms such as NH_4^+, or NO_3^-. Only certain prokaryotic organisms have the capability of transforming N_2 to NH_4^+, (nitrogen fixation). We conducted experiments using extant nitrogen fixing organisms (*e.g.*, *Beijerinckia, Azomonas, Azotobacter, Clostridium, Bacillus*, cyanobacteria), and have shown that at the low pN_2 of early Mars (18 mb), these organisms are able to fix nitrogen (*e.g.*, Figure 1). Thus, the low pN_2 of early Mars would not have prevented the evolution of a biological nitrogen fixing system as we know it.

In addition, analyses based on computer models of abiotic processes of CO_2 loss from Mars suggest that the CO_2 from the atmosphere may have precipitated as carbonates and be buried within the Martian regolith. We are currently investigating the carbon cycle of perennially frozen lakes in the dry valley of Antarctica. These lakes have been purported to be a model system for the ancient Martian lakes. By understanding the dynamic balance between the abiotic *vs.* biotic cycling of carbon within this system, we are gathering information that will enable us to interpret data obtained by a Mars rover with respect to possible carbonate deposits and the processing of carbon by biological systems. These ancient carbonate deposits, and other sedimentary units would contain traces of biological signatures that would hold the key to understanding the origin and evolution of life on Mars, as well as on Earth.

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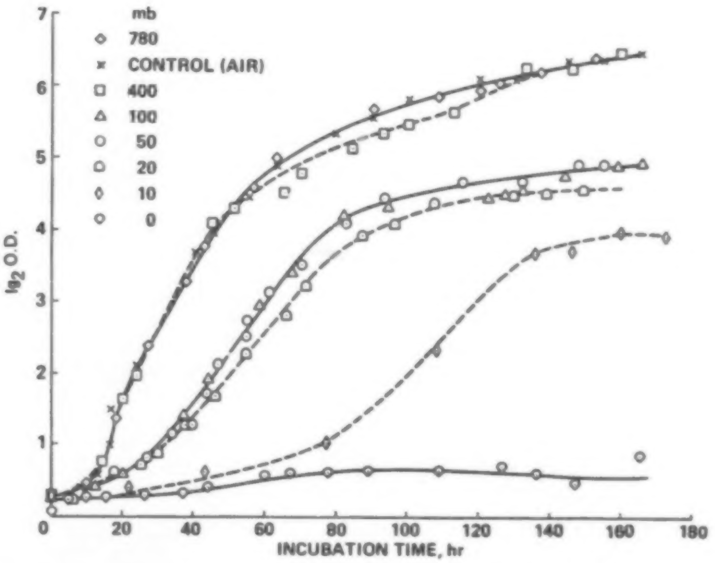

Figure 1. Growth of *Azotobacter vinelandii* under various partial pressures of dinitrogen in a nitrogen free medium. Growth was measured turbidimetrically with a Klett-Summerson Colorimeter using a red (#66) filter.

N89-18335

MARTIAN SEDIMENTS AND SEDIMENTARY ROCKS;

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Martian sediments and sedimentary rocks, clastic and non-clastic, should represent a high priority target in any future return-sample missions. The discovery of such materials and their subsequent analysis in terrestial laboratories, would greatly increase our understanding of the Martian paleoclimate.

The formation of Martian clastic sedimentary rocks, under either present, low-pressure, xeric conditions or a postulated, high-pressure, hydric environment, depends upon the existence of a supply of particles, various cementing agents and depositional basins. Chemical sediments may have formed in other basins during any previous hydric phase of the Martian paleoclimate.

Viking surface imagery leaves no doubt as to the nature and supply of Martian clastic materials in the planet's post-hydric phase. Clay-boulder size particles seem to be abundantly distributed across the planet's surface. Possible depositional basins,some of which pre-date the change to xeric conditions, include grabens, channels, canyons, etched pits and impact craters. The crucial question, therefore, concerns the presence or abscence, in recent or ancient eras, of cementing agents

Terrestial cements are typically quartzose. Statistically less important cements include calcite and siderite. Cements are usually formed from either aqueous solutions, precipitating cements in the pore spaces of unlithified sediments or by pressure solution at depth. Little is known about the thickness or moisture content of the Martian regolith, though it may be possible, even today, that (a) reactions between frost/fog droplets and Martian Fe-oxides produce small quantities of Fe-oxide cement; (b) reactions between the Ca-plagioclase component of Martian basalts, the droplets and the CO_2-rich atmosphere might produce quantities of calcite in solution; and/or (c) pressure solution reactions may occur at great depth if particularly thick accumulations of sediments occur. Compaction and pressure solution, under lower Martian gravity regimes, would require more time than terrestial analogs.

The chief question here is "where to look?". The lack of any evidence for widespread Martian tectonics virtually eliminates the possibility of locating ancient, deeply buried sedimentary rocks in stratigraphically interpretable sequences. Slump debris and crater ejectas may contain ancient sedimentary rocks, but location and interpretation would be exceedingly difficult. Certain areas, such as Ganges Chasma, the horst flanks of Noctis Labyrinthus, or the valley walls evident in the "etched" and "fretted" terrain may expose very thick stratigraphic sequences, though sampling the steep slopes would present severe engineering problems. A very high resolution(mm-cm range) photographic reconnaissance of these areas would produce a quantum jump in our understanding of Martian geological history. Sampling would be confined to more horizontal(recent) surfaces. Both exploration techniques are suggested for various hypothetical Martian sedimentary rocks in Table 1.

Table 1. Sampling the Martian Sediments

CLASTIC

Type	Ex	Probability	Terrains	Feature	lat.	long.
Conglomerate						
glacial	P	good	Etched		76S	74W
	P	good	Fretted		38N	65W
	P	good	Patterned Pl.		33N	91W
fluvial	S,P	high	Channelled		23N	33W
Breccia	S,P					
fanglomerate	S,P	good	Canyon Walls	Ganges Ch	8S	46W
				Capri Ch	12S	46W
Sandstones						
aeolian	S	v.high	Old cratered		47S	160W
fluvial	S	v.high	Channelled	Chryse P.	23N	33W
			Old cratered		48S	98W
Arkose	P	high	Graben/horst	Cerranius Fossae	24N	97W
Greywackes	-	v.low	-	-	-	-
Shales						
lacustrine	S	low	Channelled	Chryse P.	23N	33W
marine	-	v.low	-	-	-	-
paludal	-	v.low	-	-	-	-
Siltstone(loess)	S	moderate	'polar'		80S	10-90E
					85N	30E-90W
NON-CLASTIC						
Limestones & cherts	-	v.low	-	-	-	-
Evaporites	S	low	channelled	Chryse P.	23N	33W

Key: P=Photoreconnaissance Pl.=Plains Ch=Chasma
S=Direct sampling P =Planitia v=very
Probability=Probability of occurrence and detection

N89-18336

SEARCH FOR MARS LANDER/ROVER/SAMPLE-RETURN SITES - A STATUS REVIEW; Harold Masursky, A.L. Dial, Jr., E.C. Morris, M.E. Strobell, D.J. Applebee, and M.G. Chapman, U.S. Geological Survey, Flagstaff, AZ 86001

Ten Mars sites have been under study in the USA for four years (fig. 1). They are Chasma Boreale (North Pole), Planum Australe (South Pole), Olympus Rupes, Mangala Valles, Memnonia Sulci, Candor Chasma, Kasei Valles, Nilosyrtis Mensae, Elysium Montes, and Apollinaris Patera. Seven sites are being studied by the USSR; their prime sites are located at the east mouth of Kasei Valles and near Uranius Patera. Thirteen geologic maps of the first six USA sites are compiled and in review. Maps of the Mangala East and West sites at 1:1/2 million scale and a 1:2 million-scale map show evidence of three episodes of small-channel formation interspersed with episodes of volcanism and tectonism that span the period from 3.5 to 0.6 b.y. ago.

E. C. Morris has recently recompiled his geologic map of southeastern Olympus Mons (Morris, 1982) on a new base. Special computer enhancements of higher resolution Viking images allow more detailed delineation of the distribution of four basaltic units that form the volcanic construct and of an adjacent basaltic plains unit. Traverses for sampling are planned that will minimize travel over rough-surfaced flow units.

Detailed geologic mapping in the northern part of the Kasei Valles area, using specially enhanced images, shows the channel of an older, broad-valley, fluvial stage cut by a more deeply incised younger channel. Small fluvial channels formed on the sides of the main channel and deposited alluvial fan material on the valley floor; then lava flows of probable basaltic composition buried the floor of the inner channel, partly covering the alluvial fan deposits.

False-color enhancements of images in the north and south polar areas are used to plan traverses so that the lander/rover can collect samples from subjacent layered deposits and overlying materials of the layered ice cap. The proposal is to obtain and correlate 1-m-deep cores of these units at successive stations so that we can recover a continuous section of the layered deposits and the layered ice and dust of the ice cap. We anticipate that study of the ice and dust layers in these cores will reveal as much about Mars' global geologic history and climatic changes as we have learned about Earth from study of cores from the Greenland and Antarctic ice caps and deep sea cores. Viking bistatic radar data acquired near the proposed north polar landing site show it to be one of the smoothest areas on the planet (Simpson et al., 1982). This observation seems reasonable, because the polar layered deposits cover all rough impact ejecta and lava flow surfaces.

Earlier work at the Memnonia site by Scott and Tanaka (1982) shows an area containing materials of ancient cratered terrain, probable basaltic lava flows of intermediate age, and young, possibly silicic, welded tuffs. Geologic data are being recompiled on a new base map of the area. Geologic materials that range widely in age and composition should be available at this site. Geologic relations are more clear cut at Memnonia than at the Mangala site, but evidence of fluvial channeling episodes is not present.

The tectonic and geologic history of Mars, both ancient and modern, can be elucidated by sampling volcanic and fluvial geologic units at equatorial sites and layered deposits at polar sites. The evidence appears clear for multiple episodes of fluvial channeling, including some that are quite recent; this evidence contrasts with the theses of Baker and Partridge (1986) and many others that all channels are ancient. Verification of this hypothesis by Mars Observer will be an important step forward in our perception of Mars' history.

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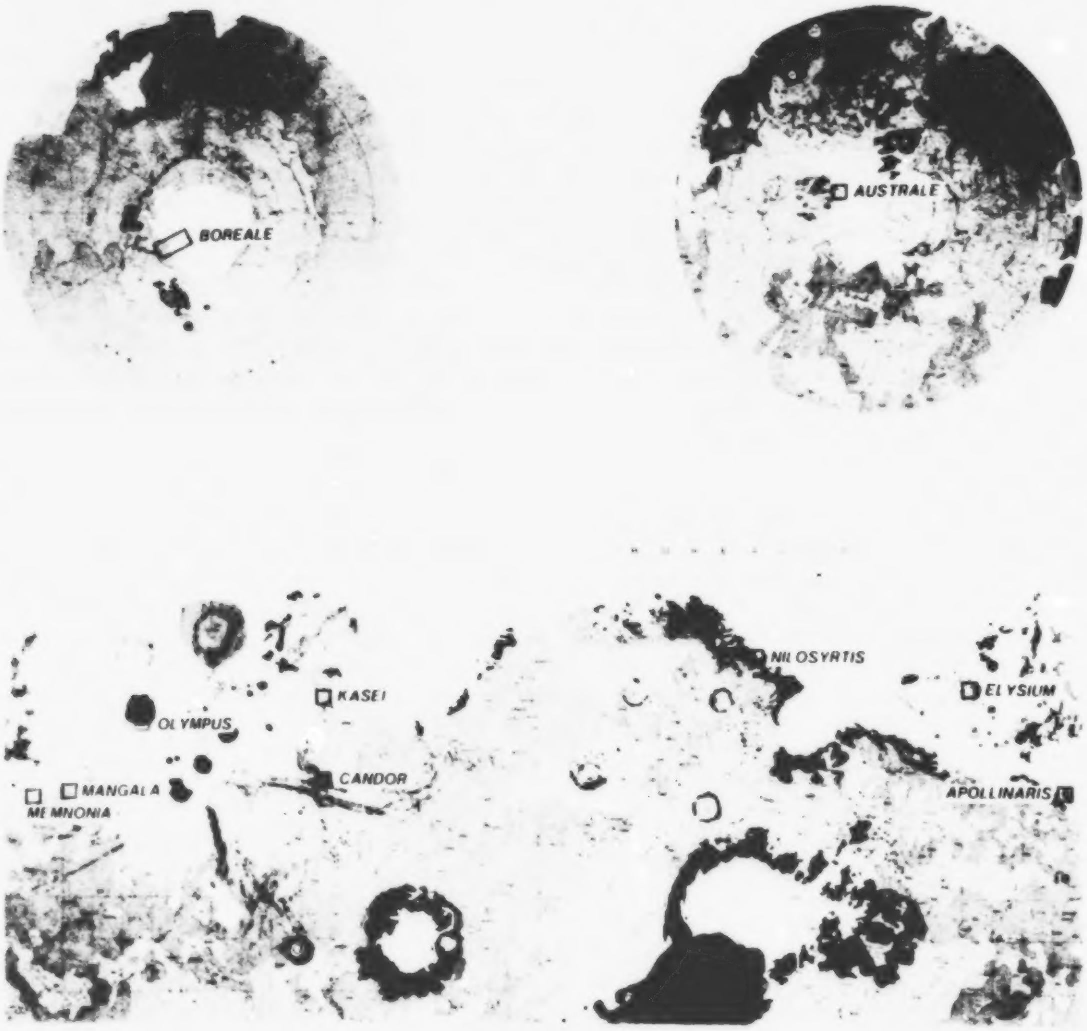
BOREALE
AUSTRALE
NILOSYRTIS
ELYSIUM
KASEI
OLYMPUS
CANDOR
MANGALA
MEMNONIA
APOLLINARIS

Figure 1. Geologic map of Mars showing the location of candidate landing sites for a future lander/rover/return-sample mission.

N89 - 18337

EARTH ROCKS ON MARS: MUST PLANETARY QUARANTINE BE RETHOUGHT?

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Recent geochemical, isotopic and rare gas studies (1) have convinced a majority of planetary scientists that the eight SNC meteorites originated on the planet Mars. In addition, three meteorites found in Antartica clearly originated on the moon (2). Detailed consideration of the mechanism by which these meteorites were lofted into space strongly suggest that the process of stress-wave spallation near a large impact (3) with, perhaps, an assist from vapor plume expansion (4), is the fundamental process by which lightly-shocked rock debris is ejected into interplanetary space. In the most plausible scenario, the SNC meteorites were ejected from Mars in the form of 10 m or greater diameter boulders 180 Myr ago by an impact that created a crater at least 100 km in diameter (5). These boulders were large enough to shield a substantial fraction of their interiors from cosmic rays until a breakup in space several million years ago exposed them to cosmic ray bombardment before they fell to the earth's surface.

The earth has also been struck by meteorites large enough to produce craters more than 100 km in diameter, such as Sudbury in Ontario, Canada (140 km diameter, 1850 Myr old), Veredefort in South Africa (140 km, 1970 Myr old), Poipgay in Siberia (100km, 39 Myr), Manicougan in Quebec, Canada (100 km, 210 Myr), and perhaps also the recently located Acraman structure in Australia (>90km, 600 Myr). In addition to the known large craters, the mounting evidence that the Cretaceous era was ended by the impact of a 10 km diameter asteroid or comet suggests that many other large impacts have occurred in Phanerozoic time whose craters either have not yet been found, or which have been modified beyond recognition. No craters have yet been located on the sea floor, which constitutes about 3/4 of the earth's present surface area.

These considerations lead naturally to the question, if Mars rocks are found on earth, why should not earth rocks be found on Mars? Furthermore, if earth rocks should find their way to Mars, might they contain spores or some sort of viable microorganisms that might then have the opportunity to colonize Mars?

To answer the first part of the question, I used the theory of spall ejection (6) to examine the mass and velocity of material ejected from the near vicinity of an impact. Since the spall mechanism only operates in the near vicinity of a free surface, the ejected rocks would all have originated from close to the surface, consistent with observations on both the Martian and lunar meteorites. The near surface is also the most biologically active region of the earth's crust, so the chance of ejecting spores and microorganisms with the spalled material is relatively high. The theory indicates that the volume of material ejected at a velocity greater or equal to greater than a predetermined velocity v_e is

$$\frac{V(\text{velocity} \geq v_e)}{V(\text{projectile})} = 4.8 \frac{P_M}{\rho \beta c_L U} \left[1 - \left(\frac{2v_e}{U}\right)^{1/3} \right]$$

where the volume is normalized by the projectile volume, ρ is the density of the target, $\beta = 4$ for most applications, U is the impact velocity, c_L is the speed of the shock wave in the target, and P_M is the maximum pressure achieved in the material ejected.

If the ejection velocity v_e is taken to be the earth's escape velocity, this equation will yield the volume of material ejected from the earth for a given velocity and size of the initial impactor. However, this equation neglects the effect of atmospheric interference, which could be of overriding importance on the earth. Numerical computations of the effect of a 10 km diameter asteroid on the earth's atmosphere (7) indicate that such a projectile clears the atmosphere away from its immediate vicinity, leaving behind a "hole" that takes minutes to close and through which early, fast spalled ejecta may escape. However, to be on the conservative side, I performed spall computations in which I assume that the atmosphere is present at its normal density. In a large impact the sheer mass of high velocity spalled material is so large that it exceeds the mass present in the atmospheric column, and so the spalled surface rocks may not be greatly hindered by the atmosphere. For the purposes of the computation I averaged the momentum of that spalled material which was ejected faster than the earth's escape velocity and the atmospheric gases along the escape trajectory. If the final velocity of both the spalled material and the atmosphere still exceeded escape velocity, then this material was counted as having escaped. If the average was less than escape velocity, then it was presumed that the material was stopped by the atmosphere and fell back to earth.

Much of the spalled material, while protected from the maximum pressure occurring in the shock wave by rarefactions from the free surface, nonetheless suffers significant shock damage. One of the SNC meteorites (EETA 79001) contains impact melt glass and may have experienced pressures as great as 50 GPa. Any organisms residing in the rock would certainly have been killed by the heat generated by the shock event. Only the rocks nearest the surface which receive the maximum protection from shock would escape heating to less than 100°C and thus retain viable microorganisms and spores. I take the corresponding shock pressure as equal to the stress necessary to crush the rock (when internal pores collapse the PdV work done during the collapse greatly enhances the energy deposition and at this point residual temperatures greatly exceed 100°C), or about 0.1 GPa (1 kilobar). The volume of ejected material escaping sterilization is thus considerably less than the total volume of spalled rock. However, this near-surface zone begins with a full complement of soil microorganisms, some of which appear likely to survive the ejection process. Behind the surface skin of spalled rock which has been raised to less than 100°C (which I will call the *fecund zone* in the following) is a larger mass of hot, sterilized rock that pushes the meter-plus-diameter boulders from the fecund zone through the atmosphere. Although some brief heating may occur at the surface of the fecund zone as the atmosphere is compressed in front of it, this heating is of short duration, since at 11 km/sec the ejecta clears the lower atmosphere in a matter of seconds. The thermal penetration depth of such a heat pulse is only a few millimeters, so that most of the ejected organisms will survive.

Figure 1 shows the volume of fecund material (which is only a few percent of the total spalled material) ejected from the earth as a function of impact velocity and transient crater diameter (the final crater will be about 65% larger than the transient crater size). Note that no ejecta escapes unless the impact velocity exceeds about 30 km/sec. This is a conservative limit: the spall model used to construct this plot assumes that no spall material is ejected faster than about 35% of the impact velocity. Direct observations on small scale impacts (8) indicate that some material may be spalled at speeds approaching 85% of the impact velocity. The contours in Figure 1 are labeled by the volume ejected in m^3. It is clear that a 50-75 km diameter transient crater (which would produce a final crater comparable in diameter to the *observed* large craters on earth) could eject roughly a million cubic meters of meter-plus-diameter boulders from the fecund zone.

It thus seems likely that the half-dozen largest impact events on earth would have each ejected considerable masses (millions of tons) of near surface rocks carrying viable microorganisms into interplanetary space. Much of the ejected debris would have been in the form of boulders large enough to shield those organisms even from galactic cosmic rays, not to mention ultraviolet radiation and low energy solar cosmic rays. Under such circumstances spores might remain viable for long periods of time. Even microorganisms active at the time of ejection might have been preserved for considerable periods by lopholization in hard vacuum. Viable organsims preserved by this process were recovered from the Surveyor 3 camera assembly after two and a half years on the lunar surface (9).

No computations have yet been performed to indicate how long earth ejecta would take to reach Mars. Similar computations on the migration of Mars ejecta to earth (10) indicate mean transit times of millions of years. However, since earth's greater mass may result in larger perturbations to the orbits of nearby debris, the transit time from earth to Mars may be considerably shorter. Some debris, of course, could make the trip much more quickly than the mean time.

Once at Mars, boulders falling to the surface would be slowed even by Mars' thin atmosphere and might even be fragmented and their interiors exposed by aerodynamic stresses at low altitudes. This process is especially important for small objects, meter size and below (11).

Terrestrial organisms in these rocks would thus have the *opportunity* to colonize the planet *if* they could find suitable conditions. I am not claiming that such conditions are present on Mars, only that it appears likely that viable terrestrial microorganisms have reached the surface of Mars by natural processes. It thus appears that the planets of the solar system are not completely isolated biologically: from time to time large impacts may inoculate planets the inner solar system with a sample of terrestrial life. The most recent such inoculation may have taken place 39 Myr ago with the event that created Popagi crater in Siberia.

In the light of these considerations the need for biological quarantine may not be as serious as was once supposed. Rocks from Mars have *already* fallen to earth without having undergone any sterilization other than that imposed by millions of years in space. Earth rocks may similarly have already reached Mars. In any event, the possibility that Mars has already been exposed to terrestrial microorganisms should be factored into any future discussions of planetary quarantine.

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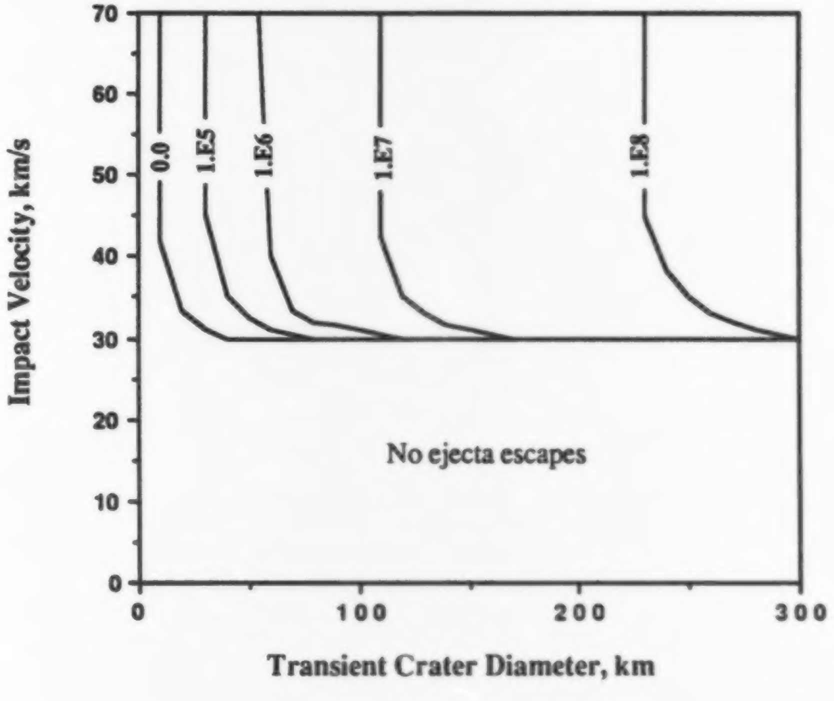

Figure 1.

ZEOLITES ON MARS: POSSIBLE ENVIRONMENTAL INDICATORS IN SOILS AND SEDIMENTS;

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Weathering products should serve as indicators of weathering environments and may provide the best evidence for the nature of climate change on Mars. No direct mineralogical measurements of Martian regolith were performed by the Viking missions, but the biology and X-ray fluorescence experiments provided some information on the physiochemical properties of Martian regolith. Most post-Viking studies of candidate weathering products have emphasized phyllosilicates (e.g., smectites) and Fe-oxides; zeolites are potentially important, but overlooked, candidate Martian minerals [1].

Zeolites would be important on Mars for three reasons. First, they are major sinks of atmospheric gases and, per unit mass, are stronger and more efficient sorbents than are phyllosilicates. Second, they can be virtually unique sorbents and shelters for organic compounds and possible catalysts for organic-based reactions. Finally, their exchangeable ions are good indicators of the chemical properties of solutions with which they have communicated. Accordingly, the search for information on past compositions of the Martian atmosphere and hydrosphere should find zeolites to be rich repositories.

Zeolites in Terrestrial Soils: There are two primary sources of zeolites in terrestrial soil. Zeolites can crystallize in situ during soil formation (i.e., pedogenic) or they can be inherited from the parent rock or from some other distant source (i.e., lithogenic). Zeolite occurrences in soils can be classified as follows: (1) pedogenic zeolites in saline, alkaline soils of non-volcanic origin; (2) pedogenic zeolites in saline, alkaline soils of volcanic origin; (3) lithogenic zeolites in soils from residual volcanic parent materials; (4) lithogenic zeolites in soils from eolian additions or fluvial deposition; and (5) zeolites in other soil environments. Most natural zeolites in weathering environments occur in arid climates.

There are over 40 naturally occurring zeolites and over several hundred synthetic zeolites with no natural counterparts. Clinoptilolite appears to be the most abundant zeolite found in soils, however, analcime, chabazite, heulandite, mordenite, phillipsite, natrolite, gismodine, stilbite, and laumontite have all been reported. Several of the more common zeolites found in soils are listed in Table 1.

Formation of Zeolites: The formation of analcime, phillipsite, and chabazite (low Si/Al atomic ratios; see Table 1) in soils usually requires alkaline pH solutions (sometimes >9) coming into contact with an aluminosilicate source (e.g., basaltic glass). High pH conditions favor the dissolution of the aluminosilicate (generally volcanogenic) source material which supplies Si and Al along with alkali and alkaline earth cations (e.g., Ca^{2+}, Na^+, K^+, and Mg^{2+}) into soil solution. Pedogenic zeolites (e.g., analcime and phillipsite) will form in situ once the soil solution becomes saturated with respect to the zeolite during evaporation of soil

TABLE 1. Representative unit-cell formula and selected chemical properties of zeolites commonly found in terrestrial soils.

ZEOLITE	REPRESENTATIVE UNIT-CELL FORMULA	Si/Al ATOMIC RATIO	pH STABILITY LIMIT[1]
Analcime	$Na_{16}\{Al_{16}Si_{32}O_{96}\}\cdot 16H_2O$	1.8-2.8	-5
Chabazite	$(Na_2,Ca)_6\{Al_{12}Si_{24}O_{72}\}\cdot 40H_2O$	1.4-3.0	-4
Clinoptilolite	$(Na_2,K_2,Ca)_3\{Al_6Si_{30}O_{72}\}\cdot 24H_2O$	4.3-5.3	<2
Mordenite	$Na_8\{Al_8Si_{40}O_{96}\}\cdot 24H_2O$	4.2-5.5	<2
Phillipsite	$(Na,K,Ca_{\frac{1}{2}})_5\{Al_5Si_{11}O_{32}\}\cdot 20H_2O$	1.3-2.9	-4

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[1] minimum pH below which structural degradation occurs.

ZEOLITES IN MARTIAN SOILS AND SEDIMENTS

Ming, D. W., and J. L. Gooding

solutions near the surface. Analcime and phillipsite (zeolite ZK-19) have been synthesized from synthetic basaltic glass using various salt solutions under mild hydrothermal conditions (temperatures < 160°C) in the laboratory (Ming, unpublished data).

The Si-rich zeolites (e.g., clinoptilolite and mordenite) commonly form by the alteration of Si-rich tuffaceous sediments (e.g., rhyolitic glass) in open hydrologic systems. Ground waters percolating through volcanic sediments become enriched with Si, Al, and alkali and alkaline earth cations. Once the solubility of clinoptilolite or mordenite is exceeded, the zeolite precipitates in areas where volcanic glass has dissolved [2]. In most terrestrial weathering environments (i.e., soils), clinoptilolite and mordenite have remained as residual mineral phases during weathering of zeolite-rich, volcanic parent materials. Clinoptilolite and mordenite, as well as other zeolites, may be removed from erosional surfaces by wind and water and transported considerable distances before being deposited at the soil surface [3,4].

Zeolite Formation on Mars: Most of the Martian weathering products are thought to have altered from mafic and ultramafic rocks [5-7]. Hence, it would appear the Si-poor zeolites (e.g., analcime, phillipsite, and chabazite) would be favored to form over Si-rich zeolites (e.g., clinoptilolite). Rocks with less aluminum, though, such as the putative Martian parents of shergottite meteorites, might actually favor clinoptilolite or other zeolites that form at higher Si/Al ratios. Also, Antarctic analog studies of potential Martian weathering processes suggests the formation of chabazite. Berkley and Drake [8] found chabazite in Dry Valley Drilling Program cores as a hydrothermal alteration product of basalts; whereas, Gibson et al. [9] have reported in situ formation of chabazite in the active saline, alkaline zone of a Dry Valley soil. Zeolite-like phases are also suspected as weathering products in Antarctic meteorites [10].

The in situ formation of clinoptilolite or mordenite in terrestrial soils is virtually unknown. In fact, to the best knowledge of the authors, only one occurrence of in situ clinoptilolite formation has been reported in a weathered sodic soil of Canada [11].

If zeolites do exist on the surface of Mars, they probably formed in an ancient Martian weathering environment or have been removed from an erosional surface by eolian processes and deposited on the surface In the present Martian weathering environment, zeolites may exist as metastable phases. The high atmospheric CO_2 and high concentration of sulfur found in the eolian sediments analyzed during the Viking Mission [12] suggest that those surface materials formed in an acid sulfate weathering environment. Most zeolites are unstable in acid environments [3] with the exception of the highly siliceous zeolites (e.g., clinoptilolite and mordenite). Hence, clinoptilolite and mordenite may have a better chance of surviving compared to the Si-poor zeolites in the present Martian environment.

Sampling on Mars: Zeolites should be sought on Mars in pyroclastic deposits, altered impact rocks, and in soils. In addition, the low densities and large aspect ratios expected for zeolite crystals would favor their extended suspension in the Martian atmosphere so that atmospheric dust should also be collected.

Martian zeolite samples must be carefully preserved to prevent degradation and loss of information that they should contain. Zeolite-bearing samples should be kept sufficiently cold to minimize both gaseous and fluid exchange reactions between zeolites and Martian atmophile elements that might modify their usefulness as fossil weathering products.

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WHAT FERRIC OXIDE/OXYHYDROXIDE PHASES ARE PRESENT ON MARS?

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INTRODUCTION

The weathering history of Mars can be deduced largely from the mineralogy and distribution of ferric oxide/oxyhydroxide phases. As discussed below, some insights can be gained through spectrophotometric remote sensing, but absolute determinations must depend on direct laboratory analysis of returned martian samples.

PUTATIVE FERRIC OXIDE/OXYHYDROXIDE PHASES

Spectral features generally attributed to ferric iron in the remotely-sensed spectral data of Mars are a weak absorption edge extending from ~400 nm to a relative reflectivity maximum at ~750 nm, inflections within the edge at ~520 and 630 nm, and a shallow band minimum near 870 nm [e.g., 1]. Certain poorly crystalline materials formed in the terrestrial weathering environment have similar spectral characteristics, implying to some [e.g., 2, 3] that the dominant ferric-containing phases on Mars are also poorly crystalline. The implication is that specific mineralogical assignments are not possible, although [4] has shown that oxide/oxyhydroxide as opposed to silicate phases are probably involved for some of the terrestrial analogue samples. The positions of the ~520, 630, 750, and 870 nm features in the martian spectra correspond to spectral features in powders of crystalline hematite (α-Fe_2O_3) [e.g., 5], but the phase is not considered to be present by [2, 3]. Apparently, this is because of significantly reduced spectral contrast for the martian spectral features as compared to those for pure hematite powders and because hematite was not found in the XRD data of the spectral analogue samples.

Other ferric oxides/oxyhydroxides have been proposed as mineralogies for the martian surface on the basis of the Viking magnetic properties experiment. According to [6, 7], the results indicate that the surface material contains a highly magnetic component. Because it is strongly magnetic, [6, 7, 8, 9] argue that maghemite (γ-Fe_2O_3) is this component. [10] suggested δ-Fe_2O_3, but this idea is discounted by [9] because the phase is apparently not naturally occurring on Earth and because it is not stable under present martian conditions. However, the stability argument can also be made against the presence of maghemite as hematite is presently the stable phase under present martian conditions [e.g., 11]. [9] do acknowledge that superparamagnetic hematite (sp-Hm) is a possibility, but they consider it unlikely because in their judgment the very small particle diameter range implied by sp-Hm (less than ~20 nm) is too restrictive.

In a recent study, [12] have shown that hematite particles imbedded in a matrix material and present in a size range including bulk-Hm (larger than ~20 nm) and sp-Hm can account for the spectral and magnetic properties of the martian surface. As shown in Figure 1, a mixture of a sample of silica gel containing sp-Hm and one containing bulk-Hm produces a sample whose spectral features are like those observed for Mars in that the position of the bulk-Hm spectral features are present but with reduced spectral contrast. Thus, because of its diagnostic features, the spectral evidence for the presence of bulk-Hm on Mars is particularly compelling. Bulk-Hm is not sufficiently magnetic (J_s ~ 0.4 emu/g [e.g., 5]), but sp-Hm is sufficiently magnetic (J_s ~ 5(2) emu/g [12]), to account for the results of the Viking magnetic properties experiment. The assertion of [9] that the size range for sp-Hm is too restrictive to be important in geologic processes is contrary to terrestrial experience. Sp-Hm and other superparamagnetic ferric oxide/oxyhydroxide phases are commonly observed and, in some cases, are the dominant ferric-containing phase in oxidizing terrestrial environments [e.g., 13, 14].

GROUND TRUTH

Although the presence of hematite on Mars is definitely indicated, its abundance is not known and the presence of other ferric oxide/oxyhydroxide phases cannot be excluded with presently available data. Samples of the martian surface would permit definitive determination of the nature of ferric oxide/oxyhydroxide phases and their relative concentrations. This is the case provided that the samples are properly selected on Mars, properly stored during the return trip, and properly handled and analyzed in the laboratory. Core samples are probably the best sampling strategy because stratigraphy is preserved. A soil core provides a sequence of soils with different surface exposure ages; the span of the exposure ages depends on the mixing rates on Mars. It is possible that the nature of the ferric oxide/oxyhydroxide phases change with depth in response, for example, to external energy (e.g., UV radiation, particulate radiation), to aging, or to thermal gradients. A rock core would establish the extent to which oxidation is a surface or bulk phenomenon for surface rocks.

The ferric oxide/oxyhydroxide phases on Mars are likely a product of martian weathering processes. To prevent degradation of the samples (especially soils) on the return trip due to "weathering" in the sample container, the samples must be kept as cold as possible. As a minimum requirement, the samples should be kept at or below their collection temperature. Sample containers with iron-bearing walls should be avoided because of potential decomposition of the walls to ferric oxide/oxyhydroxide phases; a teflon container is suitable.

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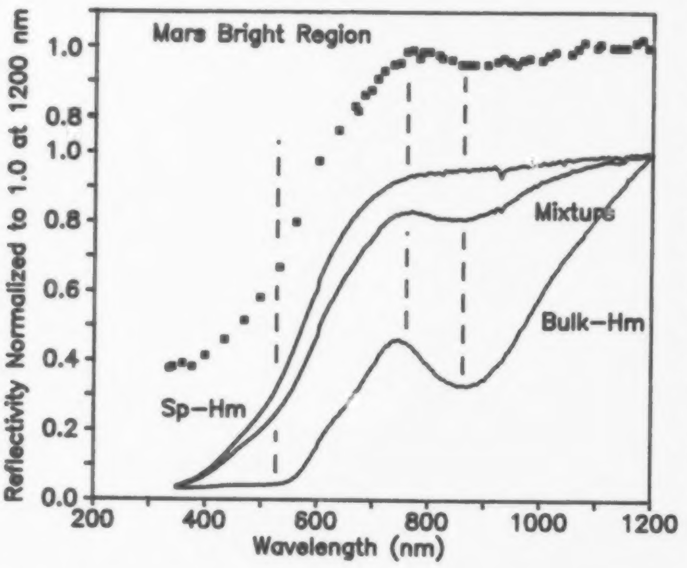

Figure 1. Normalized reflectivity spectra for average Mars bright region [from 1], sp-Hm and bulk-Hm particles supported on silica gel, and a mixture of the sp-Hm and bulk-Hm (2.8 wt. %) samples.

N89-18340

ABSOLUTE AGES FROM CRATER STATISTICS: USING RADIOMETRIC AGES OF MARTIAN SAMPLES FOR DETERMINING THE MARTIAN CRATERING CHRONOLOGY;

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In the absence of dates derived from rock samples, impact crater frequencies are commonly used to date martian surface units (1-4). All models for absolute dating rely on the lunar cratering chronology (integrated cratering rate on the moon vs. elapsed time resp. age as derived by relating crater frequencies at the Apollo landing sites to radiometric ages of the lunar rocks from those sites) and on the validity of its extrapolation to martian conditions. Starting from somewhat different lunar chronologies, rather different martian cratering chronologies are found in the literature as discussed by (2,3). Currently favored models of (1) and (3,5) are compared in Fig. 1. The differences at old ages ($> 3.5 \cdot 10^9$ years) are insignificant, the differences at younger ages ($< 3.8 \cdot 10^9$ years) are considerable and give absolute ages for the same crater frequencies as different as a factor of 3. The total uncertainty could be much higher, though, since the ratio of lunar to martian cratering rate which is of basic importance in the models is believed to be known no better than within a factor of 2. Thus, it is of crucial importance for understanding the evolution of Mars and determining the sequence of events to establish an unambiguous martian cratering chronology from crater statistics in combination with clean radiometric ages of returned martian samples.

For the dating goal, rocks should be as pristine as possible from a geologically simple area with a (desirably) one-stage emplacement history of the local formation. We need as a minimum at least one highland site for old ages, two intermediate-aged sites (Lunae Planum age to northern plains ages), and one very young one (Tharsis volcanoes or young surrounding plains).

It is especially important, as seen in Fig. 2, to determine the knee in the chronology, where the high decaying post-accretional cratering rate bends over to a constant rate, i. e. between Early Hesperian and Early Amazonian time. The actual position in time of the transition from decaying flux to steady flux (if the analogy to the lunar case holds at all) determines whether Mars developed very rapidly in the beginning with e. g. fluvial activity concentrated very much in the interval 4 - 3 billion years ago, or whether there was prolonged activity possibly until very recently. All evolutionary models of the surface and atmosphere as discussed by (6,7,8) do critically depend on such age information on a global scale. Age information on a global scale through careful calibration of the martian cratering chronology is essential for understanding the history of chemical differentiation of Mars. Calibrating the martian cratering chronology for global absolute age measurements should be one of the prime goals of a Mars Rover/Sample Return mission.

Fig. 1: Comparison of Hartmann's (1981) and Neukum's (1981, 1983) martian cratering chronology models.

Fig. 2: Stratigraphic relationships and minimum radiometric age/crater frequency data points (circles) needed to establish the martian cratering chronology.

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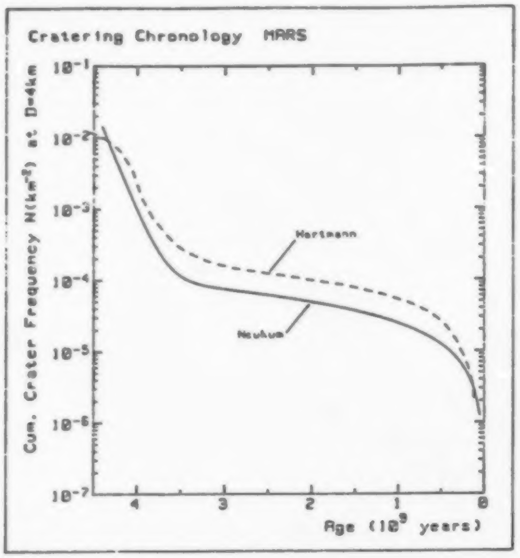

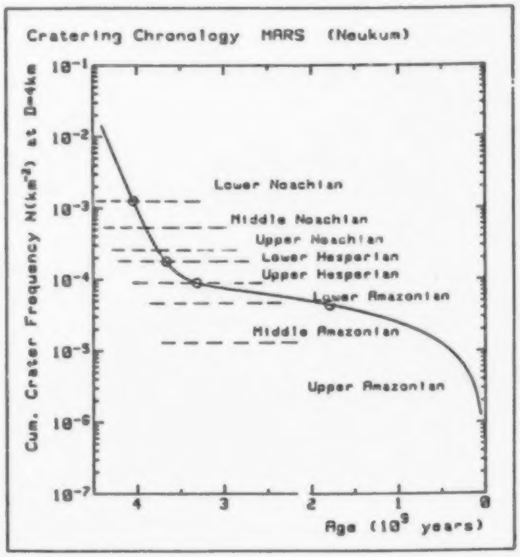

N89-18341

IN SITU MINERALOGICAL-CHEMICAL ANALYSIS OF MARTIAN MATERIALS AT LANDING/ROVING SITES BY ACTIVE AND PASSIVE REMOTE SENSING METHODS;

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Remote sensing of the martian surface from the ground and from orbiting spacecraft has provided some first-order insight into the mineralogical-chemical composition and the weathering state of martian surface materials (1,2,3,4). Much more detailed information can be gathered from carrying out such measurements in situ at the landing sites or from a rover in combination with analogous measurements from orbit (or making use of previous orbital data). Measurements in the wavelength range of ∼ 0.3 µm to ∼ 12.0 µm appear to be suitable to characterize much of the physical, mineralogical petrological and chemical properties of martian surface materials and the weathering and other alteration processes that have acted on them. It is of particular importance to carry out measurements at the same time (or near-simultaneously) over a broad wavelength range since the reflectance signatures are caused by different effects and hence give different and complementing information. (Electronic transitions, charge transfer lands of iron oxides: UV to near infrared; OH overtones, layered silicates: near to mid infrared; restrahlenbands, molecular composition of minerals: thermal infrared (5)). It appears particularly useful to employ a combination of active and passive methods because the use of active laser spectroscopy (laser diodes or CO$_2$-laser) allows to obtain specific information on thermal infrared reflectance of surface materials. Compared to passive optical thermal-infrared sensors, the active sensing method is little affected by parameters like grain size and roughness of surface materials (6,7), does not depend on temperature effects and can be used during day and night time. In the past decade the impact of active laser systems on terrestrial surface materials mapping (7-10) could be clearly demonstrated by ground based and airborne measurements. Earth orbiting space missions are planned for the end of the eighties.

It seems to be evident that a spectrometric survey of martian materials has to be focused on the analysis of altered and fresh mafic minerals and rocks, water-bearing silicates and possibly carbonates. Examples for such materials are given in Figure 1, displaying the potential of combined passive visible/near infrared and active laser thermal infrared spectroscopy. Graph 1 of Fig. 1 displays the spectrum of montmorillonite, a typical weathering product of mafic rocks. This mineral has characteristic spectral features in the near and thermal infrared (around 2.2 µm and 9.4 µm). Due to the fact, that other layered silicates show comparable spectral signatures in the near infrared, only the combination of NIR and TIR spectral data enables to detect the mineral (10).

Graph 2 and 3 of Fig. 1 give the reflectance spectra of fresh rock samples of granite and dunite. Those samples display characteristic spectral features in the thermal infrared, due to the restrahlenbands of olivine, serpentine, quartz and feldspars. Graph 4 of Fig. 1 shows the carbonate (limestone) signature at 2.35 µm and the typical increase of reflection intensity from 9.6 µm to longer wavelengths..

On-site (lander, rover) measurements of martian surface materials by application of the proposed remote sensing methods will achieve the following goals:

a) characterising the landing/roving sites and surroundings by photometrically and spectroscopically mapping martian soils and rocks;

b) gathering photometric/spectroscopic data of landing/roving site materials for orbital data evaluation and separation of surface and atmospheric (aerosol) spectral signatures;

c) pre-selecting samples for further analysis by other instruments of a lander or rover (X-ray, γ-ray, mass spectrometer);

d) selecting materials (soils and rocks) for sample return purposes and further analyses back on earth, including lab analyses of the spectral reflectance properties for obtaining "ground truth" data from martian samples in the lab in combination with the in situ measurements at the landing/roving sites for the interpretaion of orbital remote sensing data.

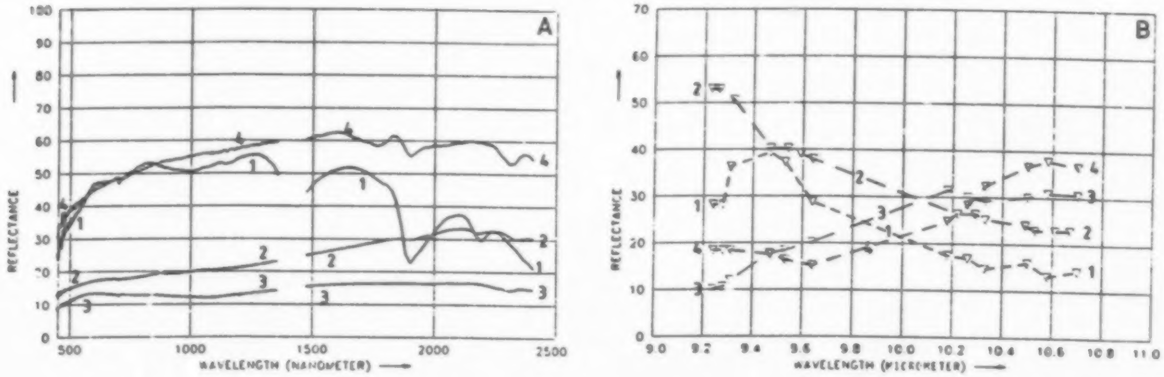

Fig. 1. Reflectance spectra of montmorillonite (1), granite (2), dunite (3), and limestone (4), in the visible/near-infrared (left) and thermal-infrared (right, CO_2-laser spectrometer).

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N89-18342

SAMPLES FROM MARTIAN CRATERS: ORIGIN OF THE MARTIAN SOIL BY HYDROTHERMAL ALTERATION OF IMPACT MELT DEPOSITS AND ATMOSPHERIC INTERACTIONS WITH EJECTA DURING CRATER FORMATION.

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The origin of the martian soil is an important question for understanding weathering processes on the martian surface, and also for understanding the global geochemistry of Mars. Chemical analyses of the soil will provide a unique opportunity to examine what may be a crustal average, as studies of loess on the Earth have demonstrated [1]. In this regard the origin of the martian soil is also important for understanding the chemical fractionations that have affected the composition of the soil. Several processes have been suggested that are likely to contribute to the martian soil. Processes connected with volcanism include palagonitization of basaltic melts [2], and alteration of volcanic glass under ambient conditions [3]. Processes connected with impacts include alteration of impact-produced glass under ambient conditions [3], alteration of hot ejecta during the actual ejection of the material from the crater [4] and hydrothermal alteration of impact deposits [5,6]. Recent investigations of terrestrial craters and experimental studies have provided strong support for the role of impact related processes in martian soil formation. Investigations of terrestrial craters have shown that hydrothermal alteration is commonly found in impact crater deposits [7]. Studies at the Ries crater in West Germany have shown that clays formed by hydrothermal alteration are very abundant in suevite deposits, where clay contents of 15 wt% are found [6,8]. The mineralogy of the clay, which is montmorillonite with no interstratified illite, indicates a low temperature origin for the clays, suggesting that most of the hydrothermal alteration takes place after the impact deposits have cooled below the boiling point of water [6]. This stage of the cooling history of an impact deposit will also be the longest in duration due to low thermal gradients and the absence of heat transport due to boiling and loss of steam.

Experimental alteration studies of highly shocked minerals have shown that dissolution of the minerals is greatly enhanced, even when the increase in surface area is accounted for [9]. This process may enhance the production of clays by hydrothermal alteration of shocked minerals. The alteration of shocked minerals under ambient conditions may also be possible, in contrast to the conclusion of Gooding [10] who considered the thermodynamic stability of unshocked silicate minerals on the martian surface.

Evidence, however, for the rapid alteration of material during the process of ejection from a crater [4] has not emerged. Experimental studies do not indicate evidence for this mechanism [11], and the low temperature nature of the clays found at the Ries does not lend support to this idea [6].

Many questions remain about the importance of hydrothermal alteration of impact deposits on Mars. This mechanism is apparently most effective on suevite deposits, but it has been argued that the amount of impact melt generated at craters where suevite is found, especially at the Ries, is much less than in craters with coherent melt sheets [4]. However, if a significant fraction of the clay matrix in the suevite at the Ries was originally impact glass then the volume of impact melt in the deposits may be similar to craters with coherent melt sheets [8]. In addition, the central

10 square kilometers of the Ries basin has not been explored by drill holes, leaving the possibility that a coherent melt sheet could be present. The question of whether suevite deposits are common on Mars is also unknown. Another conclusion of Kieffer and Simonds [4] is that suevite deposits are formed by impact into water-bearing sedimentary rocks, which might be common on Mars. At the Ries, however, which formed in a target with 500 m of sedimentary cover, the clasts in the suevite consist almost entirely of the underlying crystalline basement [8]. The formation of suevite may still be connected with the presence of water-bearing materials, but the actual mechanism may be connected with atmospheric interactions instead of processes within the crater.

The importance of atmospheric effects during large impacts has been emphasized by the studies of the K/T boundary event on the Earth. Unfortunately, only limited evidence remains at terrestrial craters because of erosion. At the Ries, such evidence includes the indication that outside of the crater the suevite was not deposited from a rapidly flowing base surge, since the contact of the suevite with the underlying ejecta deposits is undisturbed [6]. This may indicate interaction of the ejecta with the atmosphere that could involve a late-time circulatory motion of the decelerated ejecta cloud [12]. Within the crater the presence of a layer 20 to 60 m thick containing accretionary lapilli at the top of the suevite suggests the possible existence of a fireball type of cloud over the crater itself [13]. Determining the presence or absence of suevite deposits in martian impact craters and obtaining evidence of atmospheric effects during formation of martian craters will help address the nature of crater formation on planets with atmospheres.

Sampling strategy: Investigation and sampling of a large martian crater will represent the first detailed study of an impact crater on another planet. Questions regarding hydrothermal alteration of impact produced materials could be explored with samples from martian craters. Since Mars is inferred to have had a denser atmosphere in the past, when water was more available, samples from a relatively old crater may be most desirable. Ideally samples from within the ejecta blanket external to the crater should be sampled as well as the impact deposits within the crater itself. A core sample within the crater could sample both the fall-back deposits that record evidence of atmospheric interactions, and impact melt deposits, although drilling to tens of meters depth might be required. An old eroded crater may provide surface exposures of these deposits. Samples from younger craters should also be sought because they are more likely to preserve evidence of atmospheric interactions. For studying global geochemistry from soils, samples of widely differing ages should be sought.

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N89 - 18343

MARTIAN OXIDATION PROCESSES AND SELECTION OF ANCIENT SEDIMENTARY SAMPLES FOR BIO-ORGANIC ANALYSIS;

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We summarize here the results obtained by the Viking Missions concerning organic and biological analysis and indicate that these results do not preclude the existence in buried or protected regions of the planet or organic molecules or fossil life. Then we suggest the use of an automated instrument for the analysis of samples obtained from certain regions of the Planet, as a preliminary step before they are selected, retrieved, and returned to Earth for more complete analysis.

1. Viking organic and biological analysis. Samples from the surface of Mars were analyzed by the two Viking landers, at two different sites, Chryse and Utopia regions. Being the first two soft landing missions, the sites were selected for the safety of landing, not their biopotential. No organic matter was found at either site by the pyrolysis-gas chromatograph-mass spectrometer (GC-MS) at detection limits of the order of parts per billion and for a few substances closer to parts per million. On the other hand, two of the biological experiments, the Labelled Release (LR) and the Gas Exchange (GEX) experiments gave quite positive results. Two alternative possible interpretations were advanced for the positive results: Either very active biological processes or chemical processes brought about by a chemically active Martian soil. The latter view advanced by the author has been found to account for most of the observations (1).

2. The positive biological results. Chemical oxidation as an explanation. It was proposed that hydrogen peroxide or other oxygen-bearing species in the Martian soil caused the oxygen to be released in the GEX experiment. The peroxide, in conjunction with the iron oxides of the Martian soil would also cause the oxidation of the carbon -14 formate in the LR experiment. In support of this proposal were several facts: (a) Upon a second injection of nutrient solution containing the labelled substrates into the chamber of the LR experiment no more labelled carbon dioxide release was observed, but rather a reabsorption of some of the previously generated carbon dioxide took place. (b) The amount of labelled carbon dioxide (in equivalents) generated, was always below that corresponding to the number of equivalents of formate present in the sample, even though the sample contained many more equivalents of other labelled substrates. (c) It is known that formate is readily oxidized by hydrogen peroxide in the presence of certain iron oxides. (d) These inorganic oxides are present in the Martian soil. (e) The amount of oxygen released by the independent GEX experiment was of the same order of magnitude as that required for the oxidation of formate to carbon dioxide.

3. The negative organic analysis results. Photo-oxidation as an explanation. The observations which provided the most conclusive evidence for the absence of terrestrial-type life on Chryse and Utopia regions were the negative results obtained by the Viking GC-MS instrument on a number of surface and subsurface samples. These two sites of Mars contain no traces of organic compounds. This was in contrast to the results obtained from the Moon, since a few parts per million of carbon compounds were found in most lunar soil samples analyzed. This result was also surprising because, in addition to any organic compounds which may have been formed in earlier times, Mars has supposedly received during its geological history carbon compounds from cometary and meteoritic influx. How can this apparent paradox be explained? By photo-oxidation. There is a significant flux of ultraviolet radiation (200 to 300nm) reaching continuously the planet's surface, which in the presence of oxygen and other oxidizing species in the Martian atmosphere and regolith is capable of destroying by photochemical oxidation most of the organic compounds in relatively short periods of time in a geological scale. Laboratory experiments under simulated Martian conditions have confirmed the efficiency of these photo-oxidation processes.

4. Earlier Mars conditions. All of the above facts about the lack of evidence for life and organic matter at the two Viking sites do not rule out the possibility that organic compounds, and

perhaps also life, may have been generated shortly after the planet was formed. One would expect more favorable conditions for the generation of organic matter and life during the first 1 billion years as a consequence of a more benign climate and the contribution by late accretion processes of water, as well as, organic compounds from comets and other sources. Indeed, the extensive data obtained by the Mariner 9 and the Viking orbiters, and recent interpretations of the data, suggest that during the first two billion years substantial amounts of liquid water were present on Mars, which caused the formation of Martian channels, valleys, and river basins, as well as other sedimentary layered terrains.

5. Criteria for the selection of Martian samples. It is important to realize the significance of the above oxidative processes in any plans for the retrieval of any samples containing prebiologically synthesized organic matter or remains of microfossil life. This means that only those sites which have remained buried or protected from UV-induced photochemical oxidation processes since the organic material was laid down can be expected to contain organic matter. These considerations provide a basis for simple criteria to select Martian samples for bioorganic analysis. Obviously, they should not be surface or subsurface samples of regolith which has had a significant turnover rate. They should be preferably solid or compacted sedimentary rocks (e.g. cherts, stromatolitic type rocks), or alternatively they should be ancient subsurface sediments which have not been exposed to the surface during the last two thirds of the planet's history.

In line with other criteria for a Mars-Rover Sample Return Mission, samples should be collected from different Martian areas or sites such as the following (a) Valles Marineris' subsurface samples from the bottom or the slopes of the layered terrains. (b) Subsurface samples from other presumed fluvial areas, including "river basins", "lake shores", "channels" and delta zones. (c) An effort should be made to determine the possible presence on Mars of areas where dark outcrop rocks of sedimentary origin may be found. In addition to the stromatolitic rocks from the Warawoona formation (in Australia) some of the oldest microfossils on Earth have been found in black cherts and other outcrop rocks exposed to the surface. (d) The significance of other areas such as the circumpolar regions and the circumvolcanic zones (e.g. base of Olympus Mons) should be also assessed. (e) At any rate a flexible strategy for the Rover exploration of Mars should be followed so that samples could be retrieved from any alternative sites indicating the current or past presence of ice, permafrost or transient liquid (aquifer) forms of water.

Whether any microorganisms similar to the endolithic microbiota found in Antarctica may have evolved on Mars and disappeared since then is not known. Although it is highly unlikely that they exist today these organisms offer a model for the adaptation on a harsh climate where photochemical carbon dioxide fixation could be performed within an internal microenvironment which would protect the organisms from the photodestructive UV-flux on Mars. It may be of interest to determine the possible existence in the past on Mars of similar habitats to those of Antarctica

6. Implementation of Mars Rover strategy for preliminary sample analysis, collection, and return to Earth. The implementation of a successful Mars-Rover Sample Return Mission will require, among other things, the resolution of a number of questions concerning instruments, methods, strategies, etc. such as: (a) Screening and preselection of biopotential habitats. (b) Rover strategy for sample location, collection and preliminary *in situ* examination. (c) Building a simplified Viking GC-MS instrument and possibly a Mars optical electron microscope for automatic bio-organic and microfossil analysis. (d) Sample preparation analysis and data transmittal. (e) Sample retrieval and protection for return to Earth. All these matters are very tentative and need to be fully discussed by all the interdisciplinary scientists at the Workshop who are interested in bioorganic analysis. A substantial amount of pertinent information is available from the organic analysis of meteorites, as well as lunar and terrestrial samples.

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N89-18344

DECIPHERING MARTIAN CLIMATIC HISTORY USING RETURNED SAMPLES;

D. A. Paige, D. B. Krieger (UCLA), C. A. Brigham (Caltech)

By necessity, a Mars sample return mission must sample the upper few meters of the Martian surface. This material has been subjected to a wide variety of physical processes. Presently, the most important processes are believed to be wind-driven erosion and deposition, and water ice accumulation at higher latitudes. A sample return mission represents a unique opportunity to better understand and quantify these important geologic processes. By obtaining sample cores at key locations, it may be possible to interpret much of recent Martian climatic history.

It is generally believed that the mid-latitude regions of Mars are presently undergoing net erosion. Surface material raised during great dust storms is transported to the polar regions by the Martian atmosphere and deposited. The ability of the atmosphere to lift and transport dust is a strong function of the Martian surface pressure, which is believed to undergo large variations due to quasi-periodic oscillations in Mars' orbital and axial elements (1). High-resolution Mariner 9 and Viking Orbiter images have revealed extensive layered deposits at both poles, which are believed to contain a sedimentary record of Martian climatic history. These deposits have been estimated to be on the order of 5Km in thickness (2), but the timescale for their formation is not presently clear. Pollack et al. have used dust opacity measurements at the Viking landing sites to estimate dust accumulation rates of approximately 100 meters per million years in the north polar region (3). At this rate of accumulation, the entire column of polar layers could be deposited in 50 million years. Alternatively, if the polar layered deposits accumulated gradually over the entire history of the planet, the accumulation rate would be approximately one meter per million years. Constraining the rates at which the polar layered deposits have been accumulating would be an important step toward understanding martian sedimentary processes and climatic history.

One technique that could be used to determine rates of surface erosion and deposition at low latitudes and in polar terrains involves measuring abundances of short-lived cosmogenic nuclides in near-surface samples. Short-lived isotopes such as ^{10}Be ($\tau_{1/2}$ =1.6My) and ^{26}Al ($\tau_{1/2}$=0.705My) are produced by *in situ* interactions between host rocks and incident cosmic rays. For an isotopically equilibrated rock at constant depth below the surface, the rate of production of short-lived isotopes by cosmic rays is balanced by the rate of loss by radioactive decay. If the depth of rock below the surface changes due to erosion or deposition, then the abundance of short-lived cosmogenic nuclides will not be in equilibrium. The magnitude of the departure from equilibrium depends on the fractional rate of change of nuclide production experienced by the rock (due to a change in depth) relative to the half life of the nuclide. This technique for determining erosion and deposition histories has been successfully applied to lunar samples (4,5) as well as terrestrial rocks (6).

The potential utility of this technique for Martian samples can be investigated by considering the abundances of ^{26}Al and ^{10}Be within dust grains in polar layered deposits. These isotopes are produced primarily by galactic cosmic rays with energies in excess of 100MeV and by secondary neutrons with energies less than 100MeV. ^{26}Al and ^{10}Be in polar layered deposits can be produced by a variety of nuclear reactions arising from cosmic ray-induced spallation of oxygen and silicon. Reedy and Arnold have calculated production rates for short-lived isotopes as a function of depth below the surface for lunar materials (7). The production rates for these isotopes within dust grains in the polar layered deposits are expected to be an order of magnitude less due to attenuation of cosmic rays by the Martian atmosphere and seasonal CO_2 deposits. Production rates are further reduced by water ice absorption within the layered deposits. Model calculations showing predicted ^{10}Be and ^{26}Al abundances as a function of depth will be presented for a variety of assumptions concerning the composition and depositional history of the layered deposits. Similar calculations could be used to infer depositional rates for actual samples.

A sampling strategy would involve obtaining cores from both high and low latitude locations. Cores at low latitudes are necessary to determine the range of isotopic compositions of polar layered deposit source materials. Cores within the layered deposits should contain a minimum of water ice. Coring depths should be on the order of 100 cm, which is the approximate skin depth for the decrease in production of most cosmogenic nuclides (7). Sample sizes should be large enough to obtain sufficient analytical precision to distinguish between model erosional and depositional history scenarios. We calculate that a core diameter of 1 centimeter and a typical dust layer thickness of 2 microns could yield enough sample to determine ^{26}Al and ^{10}Be abundances to an accuracy of 2% using conventional accelerator mass spectrometric techniques (8). This precision would be sufficient to infer erosion or deposition rates ranging from 1 cm per million years to 10 Km per million years. Therefore, these measurements could place important constraints on our understanding of Martian sedimentary processes and climatic history.

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CONDITIONS OF THE MARTIAN ATMOSPHERE AND SURFACE IN THE REMOTE PAST AND THEIR RELEVANCE TO THE QUESTION OF LIFE ON MARS.

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Although the Viking Landers failed to find any evidence of life on the surface of Mars, much remains unknown. Study of returned samples can answer some of these questions. The search for organic compounds, the building blocks of life forms based on carbon chemistry, should continue. Even a negative result from ultrasensitive laboratory analysis can tell us much about the present conditions and past environment on Mars. Laboratory analyses of lunar samples showed that 1.5 - 2% by weight of lunar soil is meteoritic material similar to Cl chondrites. The destruction of the infallen organics by photolysis appears to be incomplete, as simple organic molecules are present in the lunar samples (1). Since the energetic hard UV radiation required to photolyze organic molecules (2) is absorbed by Mars' CO_2 atmosphere the destruction of organics on Mars is believed to be by photocatalytic oxidation. The conditions required for such a process to take place appear to be present planetwide (3). The absence of organics under a rock (4) can be explained by the migration of free radicals from the surface, where they are created, into the interior, where they would react with any organic molecules present there. If this scenario is correct it is doubtful that endolithic life forms (5) can exist under the present Martian surface conditions. The Viking gas exchange experiment results point the way to where we should look in any future sample collection attempt.

When Mars soil was moistened O_2 and CO_2 were released. The reaction seems to be the displacement of bound oxygen by water (6). Thus, the presence of water appears to mitigate the harsh chemical environment, and the search for liquid water in pores or underground should have high priority. MECA studies suggest that a much wetter climate once prevailed on Mars (7). Close examination of river beds and "lake shores" and collection of samples from sediments could yield evidence of fossil life forms, as conditions for the origin and evolution of life appear to have been more favorable in the past not only because of wetter conditions, but a richer soil as well.

Plants readily grow on lunar soil samples when water and nutrients are added. Although Martian soil is now organic-poor the present condition may not be representative of what it was in the past. With a meteoritic infall rate three times greater than that of our Moon and assuming the same Cl chondritic composition, Martian soil should have been organically richer than lunar soil at one time (8). The infall of ancient satellites could have further enhanced the fertility of the Martian regolith. The high proportion of oblong craters on Mars is believed to have been created by grazing impacts of lost satellites. The total mass of infallen material has been estimated to be $\sim 10^{22}$ g (9). If the composition of this swarm of extinct moons is the same as that of the remnants - Phobos and Deimos (10) - a layer of organic - rich Cl chondritic material about 50 m thick would have covered Mars if spread around uniformly. The total mass of the lost satellites was most likely much greater, perhaps by more than an order of magnitude (9). Using the upper limit and assuming an average mixing depth of 1 km we estimate that the Martian regolith could have had a concentration of organic material as high as a few percent. It is interesting to speculate on what could have happened if water were added to such organically rich soil.

Some exobiologists believe that life originated on Earth with the help of $\sim 10^{23}$ g of cometary material (11); now known to be similar to ice and C1 chondrites from *in situ* measurements at Comets Halley and Giacobini Zinner. By comparison Mars also got at least an equal endowment of organic molecules, including complex amino acids. Over 99% of the ancient satellite mass impacted prior to the last episode of Martian volcanism less than 1.1 b.y. ago (9). Thus it appears that there was at least a time when an organically rich soil, thick atmosphere and running water coexisted on Mars. If life is spread by Pansperma conditions on Mars seem to have been favorable then. If life originates by chemical evolution, then whether it did or not depends critically on how long the paleoatmosphere stayed around to keep water from freezing on Mars. On Earth life originated only a few hundred million years after our planet accreted. If life had originated on Mars it should have invaded every niche as on Earth, including aquifers that may still exist under the now arid Martian surface (12).

In conclusion we emphasize that the question of life on Mars is still an open one, and deserves to be addressed to by the study of returned samples. Whether life developed and evolved on Mars or not depends critically on the history of the Martian atmosphere and hydrosphere. The exobiology of Mars is thus inextricably intertwined with the nature of its paleoatmosphere and the ancient state of the planet's regolith, which may still be preserved in the polar caps and underground. Core samples from such sites could answer some of our questions.

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CLIMATE, ATMOSPHERE, AND VOLATILE INVENTORY EVOLUTION: POLAR PROCESSES, CLIMATE RECORDS, VOLATILE INVENTORIES; J.B. Pollack, NASA Ames Research Center

Climate change on Mars has been driven by long term changes in the solar luminosity, variations in the partitioning of volatiles between the atmosphere and near-surface reservoirs, and astronomical variations in axial and orbital properties. There are important parallels between these drives for Mars and comparable ones for the Earth.

In the early history of the solar system, the Sun's luminosity was 25 to 30% lower than its current value. Yet, the Earth is known to have had water oceans and life over almost its entire history. It has been suggested that an early benign climate on Earth was due to the presence of much more carbon dioxide in its atmosphere at these early times than currently resides there. Such a partitioning of carbon dioxide, at the expense of the carbonate rock reservoir, may have resulted from a more vigorous tectonic and volcanic style at early times, which implies a faster recycling rate for carbonate rocks formed by surface weathering reactions.

Such a line of reasoning may imply that much more carbon dioxide was present in the Martian atmosphere during the planet's early history than resides there today. If atmospheric partial pressures of 1 to 5 bars were achieved, surface temperatures in excess of the freezing point of water could have been achieved. Futhermore, carbonate rocks formed by weathering reactions could have been rapidly recycled by burial and thermal decomposition at these early times. Thus, Mars could have had a wet, warm climate in its early history. If so, large quantities of carbonate rocks, formed near the end of this epoch, could be key indicators of such an early environment.

It is now widely recognized that astronomical variations of the Earth's axial and orbital characteristics have played a dominant role in causing the succession of glacial and interglacial periods characterizing the last several million years. The magnitude of the axial and eccentricity variations are much larger for Mars than Earth. Such changes on Mars could result in sizeable variations in atmospheric pressure, dust storm activity, and the stability of perennial carbon dioxide and water ice polar caps. These quasi-periodic climate changes occur on periods of 100,000 to 1,000,000 years and may be recorded in the sedimentary layers of the polar layered terrain.

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Chemical Interactions between the present-day Martian atmosphere and surface minerals: implications for sample return;

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Thermochemical and photochemical reactions between surface minerals and present–day atmospheric constituents (O_3, H_2O_2, OH, HO_2, O_2, CO, CO_2, H_2O, NO_x, etc.) are likely to produce microscopic effects on the surfaces of mineral grains observable and interpretable in returned samples of surface rocks. Relevant reactions hypothesized in the literature include conversions of silicates and volcanic glasses to clay minerals, conversion of ferrous to ferric compounds, and formation of carbonates, nitrates, and sulfates (see e.g. Gooding, 1978; Huguenin, 1982; Sidorov and Zolotov, 1986; and references therein).

Because of the importance of these types of reactions for addressing issues such as chemical weathering of minerals, biological potential of the surface environment, and atmospheric stability in both present and past Martian epochs, we emphasize the need to collect and return samples in a manner which will preserve their microscopic surface layers. If no *in situ* analyses for reactive atmospheric species is included as a part of a sample return mission we emphasize also the need to collect and return atmospheric samples with the aim of preserving as many of the reactive gaseous species as possible (*in situ* analysis is preferred).

Analyses on returned samples surfaces would include: (a) initial examination in a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) and back–scattered electron imaging to provide morphologies and major element compositions, (b) electron probe microanalysis (EPMA) to provide major element compositions, (c) detailed measurements of structures and mineralogies using transmission and analytical electron microscopy (TEM/AEM), (d) UV/vis/IR transmission spectra, (e) minor element composition and light element stable isotope measurements by ion probe, (f) INAA on microgram samples, and (g) XPS (x–ray photoelectron spectroscopy) for chemical analysis of top (tens of Å) surface layers.

These sample surface analyses combined with atmospheric analyses, *in situ* measurements of temperature and ultraviolet radiation intensities, and precise knowledge of the minerals being chemically weathered should lead to identification of the overall reactions and processes involved in the atmosphere–surface interaction.

Macroscopic products of chemical weathering reactions in past Martian epochs are also anticipated to be present in returned samples. These products are expected not only as a result of reactions similar to those proceeding today but also due to aqueous reactions in past epochs in which liquid water was putatively present. It may prove very difficult or impossible however to determine definitively from the relic product alone either the exact weathering process which led to its formation or the identity of its weathered parent mineral. The enormous advantages of studying Martian chemical weathering by investigating the microscopic products of present–day chemical reactions on sample surfaces are very apparent: the relevant atmospheric, surface, and solar radiation environments leading to chemical alteration of the minerals and glasses and the identity of the material being weathered can all be precisely defined.

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DEGASSING HISTORY OF MARS FROM MARTIAN ATMOSPHERE SAMPLES; **A.S.P.RAO, Dept. of Geology, Osmania University, Hyderabad 500 007, INDIA.**

A comparison of the abundances of ^{40}Ar and ^{4}He (radiogenic) in various terrestrial planetary atmospheres provides clues to the volcanic and tectonic histories of the planets while the amounts of primordial noble gases (^{20}Ne, ^{36}Ar, ^{84}Kr and ^{38}Xe) in the planetary atmospheres provides clues to the quantities of volatile rich materials captured by each planet. The noble gas (primordial) contents of Mars, Earth and Venus clearly show that the absolute abundances of isotopes of gases (^{36}Ar, ^{20}Ne, ^{84}Kr & ^{132}Xe) are directly proportional to the amounts of degassed CO_2 into the planets atmosphere (1).

Several basic geological units (2) (highly cratered, ancient terrains in the higher-altitudes and relatively uncratered, younger plains in the lower-altitudes) can be seen on the global geological map of Mars (Figs.1 & 2). The enormous size of volcanic and tectonic structures of Mars, despite its smaller size than Earth, provide invaluable clues to the degassing history of Mars.

Therefore the collection of samples of martian atmosphere and soil volatiles is imperative to understand the origin and evolution of the atmosphere and it interaction with the martian surface. Surface properties of martian rocks, soils, breccias and regolith and their chemistry are also generic to any discussion on the origin and evolution of the atmosphere of Mars.

The differences in absolute abundances of gases (on a gram per gram planet basis) in the planetary atmospheres are amenable to many alternative interpretations [(a) initial conditions in the composition of nebula, (b) degree of degassing, (c) escape of volatiles, (d) absorption by Martian surface and (e) size and age of the planet]. These alternative interpretations can be tested by imposing additional constraints derived from the isotopic ratios of noble gases in the atmospheres of planets.

This paper maintains that planetary volatile inventory is essential to understand the degassing history of the red planet, Mars.

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COSMOGENIC NUCLIDES: OBSERVABLE EFFECTS OF MARTIAN VOLATILES*

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Cosmic-ray-produced (cosmogenic) nuclides in returned martian samples could be used to study the amounts and distributions of volatiles in the recent past on Mars. In planning for the Gamma-Ray Spectrometer experiment that is scheduled to fly on the Mars Observer, we have done many calculations on the nuclear reactions that should occur in the martian surface, studying especially the production and transport of neutrons. We have found that three aspects of Mars can very significantly affect the production of cosmogenic products in Mars: the martian atmosphere and the presence of H_2O in or CO_2 on the surface of Mars. These volatile components can greatly affect the energy and spatial distributions of neutrons, especially those with thermal or near thermal energies, in the surface of Mars (1). In turn, these neutrons produce many cosmogenic nuclides that can be observed in samples returned from Mars.

Most cosmogenic nuclides are produced by secondary neutrons made by galactic-cosmic-ray (GCR) interactions, although a few (e.g., ^{10}Be) are mainly made by the primary GCR particles (2). The energy and spatial distributions of these neutrons are especially sensitive to certain elements with special nuclear properties, such as hydrogen and carbon (which effectively thermalize energetic neutrons). Neutron-transport calculations for objects with no atmosphere (3-5) showed that hydrogen significantly changed the depth and energy distributions of low-energy (thermal and epithermal) neutrons, increasing their flux and raising the depth of their peak intensity. However, until recently (1,6), no calculations had been done for neutron transport in Mars with its 16-g/cm^2-thick atmosphere of almost pure carbon dioxide and the variable contents of CO_2 frost and H_2O in or on its surface.

The equilibrium distribution of neutrons in Mars was calculated using the One-Dimensional, Diffusion-Accelerated, Neutral-Particle Transport (ONEDANT) code (1). The ONEDANT code was modified to include the effects of gravity and the beta decay of low-energy neutrons that escape from and then return to the surface of Mars (7). A 16-g/cm^2 atmosphere was included in all of the calculations, and the compositions of the atmosphere and surface soil as determined by the Viking landers were used in all the calculations. Many special cases involving variable amounts of and depths for H_2O or thicknesses of CO_2 frost on the surface were run. The equilibrium distributions of neutrons calculated by ONEDANT in the martian surface agreed with those from an independent set of calculations (6). Hydrogen in the martian surface rapidly thermalized neutrons and shifted their energy and depth distributions. Carbon dioxide as frost or in the atmosphere attenuated the intensity of incident cosmic-ray particles, moderated fast neutrons, and built a reservoir of low-energy neutrons that leaked back into the martian surface. The combined effects of the martian atmosphere and H_2O on the neutron distribution in Mars are illustrated in Fig. 1, which shows the neutron-capture ("GAMMA") profiles for several water contents of the surface. Relatively high water contents result in distinctive shapes for the martian neutron-capture profile not seen in other calculations with high hydrogen contents (3-5), especially just below the atmosphere-surface boundary.

To unfold the cosmic-ray record in martian samples, many products with various half-lives made by cosmic-ray particles with different energies would need to be measured. For example, ^{10}Be made by high-energy reactions, ^{26}Al made by fast neutrons, and ^{36}Cl made by neutron-capture reactions with relatively abundant martian chlorine could be used to establish the average cosmic-ray particle environment in the martian surface over the last million years (the approximate half-lives of these three long-lived radionuclides). If the systematics of these radioactivities differ from those observed for short-lived radionuclides, such as spallogenic 2.6-year ^{22}Na and neutron-capture-produced 5.27-year ^{60}Co, then we could possibly infer that changes had occurred in the martian climate (CO_2 thickness or surface hydrogen content) over the last million years. Stable cosmogenic nuclides, such as ^{21}Ne, high-energy-produced ^{3}He, and ^{36}Ar (mainly from the decay of neutron-capture-produced ^{36}Cl) could extend this comparison to longer time periods. Such studies would be in addition to those done now with cosmogenic nuclides in lunar samples, such as determining exposure ages and gardening rates of the regolith (8).

Both cores in the martian regolith down to depths of at least a meter and surface rocks would be needed to unfold the various cosmic-ray records. Care would be needed to prevent the loss of certain cosmogenic products that are volatile, such as chlorine or the noble gases, from the returned samples (9). In interpreting the cosmogenic-nuclide measurements, the sample's location and its chemical composition, especially its (and the surrounding) hydrogen content, need to be known (9).

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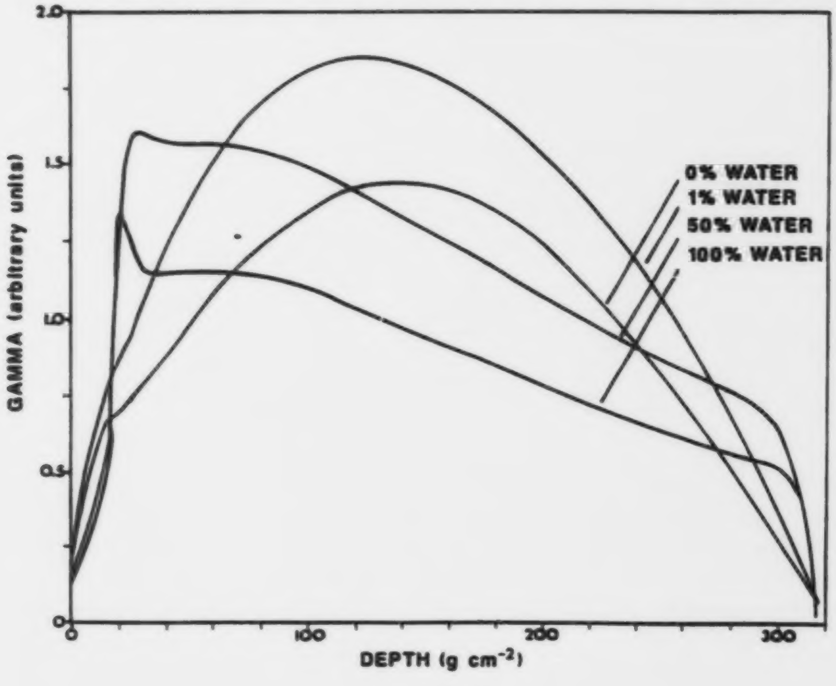
Figure 1. The relative rates for the capture of low-energy (thermal and epithermal) neutrons in Mars as a function of depth (the top 16 g cm^{-2} is the atmosphere) for water contents of 0, 1, 50, and 100%. Note the enhanced rates just below the atmosphere-surface boundary for high water contents. The sudden, sharp decreases below 300 g cm^{-2} are artifacts of the calculations.



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MARS ROVER SAMPLE RETURN: AN EXOBIOLOGY SCIENCE SCENARIO;

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A mission designed to collect and return samples from Mars will provide unique information regarding its composition, history, and evolution. At the same time, a sample return mission generates a technical challenge. Sophisticated, semi-autonomous, robotic spacecraft systems must be developed in order to carry out complex operations at the surface of a very distant planet. We have been conducting an interdisciplinary effort to consider how such a Mars mission can be realistically structured to maximize the planetary science return. Our focus has been to concentrate on a particular set of scientific objectives (exobiology), to determine the instrumentation and analyses required to search for biological signatures, and to evaluate what analyses and decision making can be effectively performed by the rover in order to minimize the overhead of constant communication between Mars and the Earth. We have also begun investigations in the area of machine vision to determine whether layered sedimentary structures can be recognized autonomously, and preliminary results are encouraging.

Investigations have shown that primordial Mars was similar to primordial Earth in many ways that are important to biological systems. Both planets were characterized by the presence of liquid water at the surface, an atmosphere of carbon dioxide and nitrogen, moderate surface temperatures, and high geothermal heat flow. These conditions are conducive to the formation of organic molecules that are thought to be the key to forming the first biologic molecules on Earth. Although there are no indications that extant life forms exist on the cold, dry, and chemically reactive surface of Mars today (1,2), the similar environments of early Earth and early Mars and the biological evolution that we know occurred on early Earth motivate serious consideration for the search for a primordial martian biosphere.

Since we know that water is the key to life on Earth, it is logical to explore areas on Mars where water may have existed for long periods of time. In our study, we have focused on the putative lake deposits in the equatorial canyons of the Valles Marineris where long-lived lakes may have once existed early in Mars' history. These deposits form plateaus of horizontally-layered material where individual layers are laterally continuous over tens of kilometers (3). Nedell *et al.* (3) concluded that deposition in standing water was the only mechanism that could readily explain the distribution, lateral continuity, horizontality, great thickness, and rhythmic nature of the deposits. The most important biological signatures to detect would be organic material, microfossils, or larger stromatolite-like structures, although the presence of carbonates, cherts, clays, and shales would also be significant. These traces of extinct biota and sedimentary deposits are all associated with liquid water.

The round-trip light time to Mars varies from 6.5 minutes during the most favorable opposition to 44.5 minutes when Mars is near solar conjunction, and communication may be regularly impossible. In addition, communication bandwidth will be a limiting resource. With these limitations in mind, we have developed a partial scenario to implement an exobiologic investigation patterned after the procedures of a field scientist. Only a limited number of small samples can be brought back from Mars and, therefore, it is most expedient to do as much of the analyses as possible insitu. We have considered survey procedures for the rover at the landing site, how to detect an outcrop and a suitable sampling site for exobiologic investigations, and how to select and analyze a sample. Instruments needed will include: infrared spectrometer, active seismic instrument, XRF, GC, and various drills, corers, etc.

We have attempted to quantify the benefits and risks of rover autonomy. Our scenario has shown that we can minimize the amount of data that must be sent back for interactive decision-making, and therefore, much time is saved by the rover doing some rudimentary interpretations. As part of a collaborative effort with SRI's vision group, we have determined that sedimentary layering can be recognized by using fairly standard mathematical techniques. This is the type of automation tool we are currently investigating, which is designed to aid, not replace the Earth–based scientist. By developing a semi–autonomous rover, the scientific productivity of a Mars Rover Sample Return Mission will be increased.

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VOLCANIC ROCKS AND THE GEOLOGIC HISTORY OF MARS. P. A. Salpas, Dept. of Geology, 210 Petrie Hall, Auburn Univ., AL 36849

A number of questions exist regarding the geology of Mars which can be addressed by the proposed Mars rover-sample return mission. These include: (1) The planet's bulk composition and chemical differentiation during formation of its core and crust. (2) The extent to which internal geologic activity continues. (3) The evolution of its atmosphere. (4) The extent and duration of fluvial processes and an accounting of Mars' volatile inventory. (5) The extent to which eolian processes are presently reshaping the surface. (6) Is there, or was there, life on Mars?

The use of a rover during the proposed mission greatly enhances the ability to investigate multiple aspects of Mars' geology and geologic history. However, the physical constraints imposed by the mobility of the rover and by the amount of sample which can be carried by it and the return vehicle may make it necessary to narrow the number of questions which can be addressed directly. Attempting to address all of the important questions may dilute the amount of information that can be obtained regarding each question and may result in no satisfactory answers. Prioritization is essential for a successful mission.

The task of setting priorities is simplified somewhat when it is considered that answers to some of these questions do not require taking samples, and that for some questions, sample location is not as important as for others. Atmospheric, weathering, sedimentary transport, and seismic studies can be conducted at most locations planet-wide, and some topics (e.g., fluvial and eolian processes, volatile inventory, surface composition) can be addressed partially by the orbiting vehicle. The choice of sampling locations will be dictated largely by those questions which, in whole or in part, require specific sites. Among these are: (1) The question of life on Mars. If life has ever existed on Mars the evidence would be found in those regions most conducive to life - i.e., wet, warm and sheltered from harmful solar radiation. (2) The volatile inventory question - do large amounts of water exist subsurface as permafrost [e.g., 1,2]? (3) The geochemical evolution of Mars. Sampling traverses through a volcanic region that possesses a diversity of rock types and ages could provide a wealth of information regarding the compositional evolution of the planet. However, such traverses would probably exclude investigations of questions (1) and (2) as the water which is sought after is most likely to be found in regions of thick regolith. Without diminishing the importance of other geologic questions, the remainder of this abstract will address Martian volcanic rocks.

It is thought that the ages of volcanic rocks on the surface of Mars range from the time of a major resurfacing event, about 3.5 to 4.0 Gy [3,4], to the relatively young rocks of Olympus Mons, about 0.2 Gy [5]. These ages are in contrast to those of Moon which are mainly ancient, derived from a major differentiation event around 4.5 Gy and a period of volcanism which ended about 1 Gy later. Unlike Earth whose rocks are relatively young, the surface of Mars has not been extensively ravaged by either a highly active atmosphere or (to the best of our knowledge) plate tectonics. The volcanic rocks of Mars will therefore contain information about processes which are "intermediate" during the compositional evolution of the terrestrial planets.

The surface of Mars presents two distinct terrains, both of which have the potential to contain valuable information regarding the composition of Mars. One terrain, comprising mainly the southern hemisphere, is ancient and heavily cratered and is the more likely of the two to provide a suite of rocks which include ancient crustal samples. However, these samples will be locked up within breccias, and we can anticipate from our experience with lunar breccias the problems of interpretation which will ensue (e.g., pristine vs. non-pristine, lack of field control). Furthermore, the ages of the ancient Martian rocks from this terrain probably do not exceed 3.5 - 4.0 Gy and therefore do not represent primordial crust such as found on Moon [3].

The other terrain, mainly in the northern hemisphere, is not heavily cratered, and contains extensive volcanic fields. Samples collected here could possess a wide range in age and afford excellent documentation of the differentiation of Mars' interior by providing samples which range from mafic [6] to felsic [7] in composition ([8] questions the evidence for silicic volcanism on Mars). A prime location for sampling is the Tharsis Plateau. This broad region of uplift straddles the boundary between the ancient, heavily cratered terrain in the south and the younger plains in the north. It has been postulated that the ages of volcanic rocks in the cratered plains of Tharsis may be as great as 3.8-4.0 Gy [4]. Young volcanic material is also to be found on Tharsis; the youngest rocks on Olympus Mons are estimated to be only 0.2 Gy [5]. The morphologies of most lava flows on Tharsis are suggestive of mafic compositions [6] but the ignimbrite province of [9] offers the possibility of finding compositionally evolved volcanic rocks on the plateau.

Sampling the rocks of the Tharsis Plateau to maximize the diversity of samples is probably impractical. To put the matter into perspective, the map distance of the cratered plains in southern Tharsis to the summit of Olympus Mons is about 4000 km. However, the Tharsis region offers the opportunity to select from volcanic rocks which span nearly the entire geologic history of Mars and document the chemical differentiation of the planet. Choice of this site might rule out visits to other geologically interesting locations.

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THE ROLE OF IMPACT CRATERING FOR MARS SAMPLE RETURN, P.H. Schultz, Dept. of Geological Sciences, Brown University, Providence, R.I. 02912

The impact process became a major focus of lunar studies during Apollo because it provided a context for understanding sample provenance, regolith evolution, smooth plains origin, the lunar time scale, magnetic field generation, lithospheric evolution, and crustal structure. Although Mars offers a much more complex geologic history (a contrasting style of volcanism/tectonism and active atmsophere/surface processes), the preserved cratering record indicates that impacts will play an important role in deciphering martian geologic history whether as a mechanism to modify the lithosphere and atmosphere or as a tool to sample the planet. Rather than reviewing lessons learned from Apollo in detail, the following discussion examines the various roles of impact cratering in adding a broader understanding of Mars through returned samples. Five broad roles include impact craters as: a.) a process in response to a different planetary impact environment; b.) a probe for excavating crustal/mantle materials; c.) a possible localizer of magmatic and hydrothermal processes; d.) a chronicle of changes in the volcanic, sedimentary, atmospheric, and cosmic influx history; and e.) a chronometer for extending the geologic time scale to unsampled regions. Three underlying philosophies are implicit. First, a limited sample return should provide the broadest range of materials and processes. Second, at least one reference time needs to be firmly established. And third, a strategy should explore what is known as well as attempt to confirm what is (believed to be) known.

Impact Process: Impact conditions at Mars differ from the Moon in three very fundamental ways: the presence of an atmosphere; presence of crustal volatiles (whether free or chemically bound); and lower impact velocities. Atmospheric density above Mars at 80 km matches the terrestrial value at 100 km; consequently, shielding of the surface from low mass impactors on the two planets is equally effective. Larger mass meteoroids will break-up due to aerodynamic forces and it has been estimated that craters smaller than 50 m would be prevented from forming (1). As a result, the martian regolith may contain a record of cosmic dust and broken meteorites unlike the lunar regolith. The presence of even the presently tenuous atmosphere also affects ejecta ballistics provided that: ejecta are small enough to be affected by air drag; the crater is large enough to eject material at high velocities; and the crater is small enough to be formed within a few atmospheric scale heights (2, 3, 4). On the basis of laboratory experiments and theoretical considerations, the present martian atmosphere may control the development of contiguous ejecta ramparts and ejecta lobes (3) as well as crater size (5). At large distances, ejecta re-entering the atmosphere develop dynamic pressures large enough (0.5 kb) to induce break-up and dispersal of weak ejecta, thereby reducing the role of secondary cratering. The addition of volatiles in the near surface result in enhanced fluidization of the ejecta (6, 7, 8), a strong precursor air blast that scours the surface to large distances (4, 9), and possibly increased crater collapse (6). Martian impactors are believed (10) to be dominated by asteroids with an impact velocity ranging from 8 to 15 km/s whereas lunar impactors may be a mix of asteroids (22 km/s) and periodic comets (40 km/s). This difference may be significant for the production of melt and vaporization (since partitioning increases as v^2) and crater aspect ratio (11).

Impact Probe: Impacts permit sampling buried materials through excavated ejecta and uplift of the crater interior. This principle was used as a rationale for Apollo landing site selection: Apollo 14 (Fra Mauro, Cone Crater); Apollo 15 (Imbrium rim); Apollo 16 (Cayley, North/South Ray); Apollo 17 (serenitatis rim). It may be even more important for Mars where a reworked or covered surface may prevent direct sampling of bedrock. The presence of an atmosphere and volatiles modifies simple ballistic emplacement and inverted stratigraphy unless smaller craters (< 1 km) are used. The atmosphere, however, could play a useful role by reducing the velocity of more distant ejecta such that primary ejecta can be sampled. With such a philosophy, an ideal site would provide a potpouri of martian processes through breccias from distant (4 crater radii) large craters, talus from an uplifted basin massif ring, debris ejected from a small crater, and surface materials reflecting a uniquely martian process (e.g., outflow channel). One possible candidate includes the base of the Isidis inner massif ring where channels weaving between massifs empty on the plains (12), where a thick transient volatile-rich debris layer once existed (13), and where small dark-haloed as well as larger impact craters insure sampling below more recent sediments. The deeply incised channels through the massif ring of Chryse provide an alternative setting and context.

Magmatic/Hydrothermal Centers: Impact basins and craters provided the primary pathways for lunar magmas. Similarly, the early volcanic history of Mars was localized by impact structures (14, 15). The addition of water, however, may have resulted in hydrothermal processes resembling the Sudbury structure on the Earth (16). Sampling this history on Mars is possible by extensive erosion and dissection of ancient impact basins along the contact between the ancient cratered uplands and northern plains. Possible candidates include craters and basins Deuteronilus Mensae where erosion has revealed roots of central uplifts and possible dikes expressed as dark linear extension of a now-missing basin ring.

Chronicle: The preservation of craters as landforms dating back to the first 0.5 by history of Mars contrasts with the Earth where the erosion rate can erase a 10 km crater in 200–300 my (17). Stable polar ice sheets, lakes, and oceanic basins are now providing a record of the terrestrial climate and cosmic flux over the last 30 my. The present plar layered terrains could provide an analogous sedimentary environment over the recent past (< 1 by) while the interiors of large (30–100 km) craters may provide a record over 3.0 by. The high rate of erosion and deposition on the Earth dilutes the cosmic flux unless a major event occurs (e.g., the putative K/T impact event). The possibly higher martian impact rate, the longer collection history, the more stable tectonic environment, the lower rate of resurfacing, and the effective atmospheric shielding all point to the possible use of isolated depositional traps as a chronicle of the martian cosmic flux. Estimates of this flux from the observed crater statistics indicate as much as 10^{21} g/100 my during the time following the Argyre impact and 10^{20} g/100 my during the emplacemnt of the ridged plains (18). A different but equally important chronicle of atmospheric conditions may be provided by the rate and style of weathering of ejecta from craters of different ages.

Chronometer: One of the most important goals of a sample-return mission is establishing a martian time-scale. Not only does this provide a time scale for geologic history but also a time scale for the impact flux on a different planet. The concept is simple but the application complex. The effects of substrate, volatiles, the atmosphere, and erosion all affect extrapolations from a single reference time; consequently, a priority must be given to different units or events, thereby limiting errors from interpolations while providing important information about cratering mechanics.

Summary: The evidence for Earth-like processes and very non-lunar styles of volcanism and tectonism may shift the emphasis of a sampling strategy away from equally (or more) fundamental issues including crustal composition, unit ages, and climate history. Impact cratering not only played an important active role in the early martian geologic history, it also provides an important tool for addressing such issues.

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MARS SAMPLE RETURN: RECOMMENDED SITES; D. H. Scott, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Ariz. 86001

INTRODUCTION

Site-selection priorities for a Mars sample return are constrained by the risks due to terrain that affect the successful descent and mobility of the sampling vehicle. At this time, evaluations of terrain roughness can be made only in a very general way. For this reason, the two candidate sites discussed are provisionally recommended primarily on the basis of their scientific value; however, no adverse surface conditions are discernible at these locations at the resolution of Viking images.

SITE-SELECTION RATIONALE

Ideally, the site should be located where a suite of rocks and soil is readily accessible to the sampling vehicle. The rocks should be in place and have a wide range in age, lithology, composition, and mode of origin. They should be correlative with other major geologic units in the global time-stratigraphic system. Some of the materials should be associated with important volcano-tectonic episodes and magmatic histories, others with fluvial, eolian, and polar processes that are indicators of climate and atmospheric history. Ultimately, the ideal site would also be in an area where evidence of present or former biological activity would most likely be found.

With our present knowledge of Mars, we have found no single locality where such optimum conditions exist. On the other hand, many areas are known where rock samples would resolve specific problem-oriented questions. Such a narrow focus, however, would leave untouched the broader aspects of Mars geology and history.

The two sample sites considered represent a compromise between broad-based objectives and specific, but highly important, problems that cannot be resolved without material samples. They were selected on the basis of information gained during the global geologic mapping of Mars (1,2,3). Locations are biased toward the western equatorial and polar regions, with which this investigator is most familiar.

SITE 1 (Fig. 1) Tharsis-Olympus Region. The location is about lat 12.5° N., long 125.5°, within the relatively flat, smooth-appearing plains member of the Olympus Mons Formation (unit Aop_1). This Upper Amazonian member is composed of some of the youngest lava flows on Mars. It extends for more than 2,000 km around the eastern and southern parts of the basal scarp of Olympus Mons. The flows embay a large block of old (Hesperian) fractured crust (unit Hf) as well as the lowermost member (unit Aoa_1) of the Olympus Mons aureole deposits of Early Amazonian age. The site is within 15 km or less of both of these older units. Sample ages and compositions of these three units would (1) reveal stages in the volcano-tectonic history of one of the largest and most geologically important regions of Mars, (2) provide an upper time limit on the cessation of major faulting in the western hemisphere, (3) closely define the time of occurrence of the last major volcanic episode of both Olympus Mons and Tharsis Montes, (4) answer controversial questions on the composition and origin of aureole deposits around Olympus Mons, (5) provide an upper limit on the time of major flooding in Kasei Valles, and (6) determine indirectly, by enabling correlations of geologic units (possibly supplemented by crater counts), the times of formation of other materials in a large area.

SITE 2 (FIG. 2) Chasma Boreale (North Polar) Region. The location is about lat 82° N., long 57°, within polar ice and layered terrain materials (units Api, Apl) of probable very late Amazonian age. The dusty ice surface appears smooth and flat to gently sloping; gentle slopes are also suggested by a broad streaked appearance such as would occur where a slightly inclined surface transects nearly horizontal layers of contrasting albedo. Samples could be obtained here from four different types of materials ranging in age from probably very recent to Hesperian: (1) Interbedded ice and dark material (silicate dust?) surrounding the landing site for tens of kilometers. (2) Grooved and polygonally patterned material (unit Hvg) underlying the layered terrain and within 25 km or less from the landing site; this material occurs in patches throughout the northern plains and south of lat 40° S. in Mare Acidalium. (3) Ejecta from a sharp-rimmed, 5-km-diameter crater within 20 km of the site; the crater (unit c) lies on grooved material (unit Hvg) and is partly embayed by layered terrain materials. (4) Cliff-forming material, appearing as a thick, massive layer, within 15 km of the site; this material of unknown age, origin, and composition underlies some layered deposits but may be interbedded with others. It appears to overlie the Hesperian grooved unit. The geological interpretation shown in Fig. 2 was made from a photomosaic (1:500,000 scale) compiled from Viking 2 images taken at approximately LS 53° (spring). A visit to this site during late northern summer would probably reveal geologic material units covered by less ice and frost.

Geological and geochemical data from these sampled materials would contribute to understanding climatic and atmospheric changes and processes affecting the development of Mars' polar caps. They would also unlock some geologic secrets of the vast northern lowlands that presently elude observation.

Other Mars sample-return sites have been investigated (4, 5, 6) that would also yield valuable data, but the two sites discussed above are believed to be among the best at this stage in our understanding of the geologic history of Mars.

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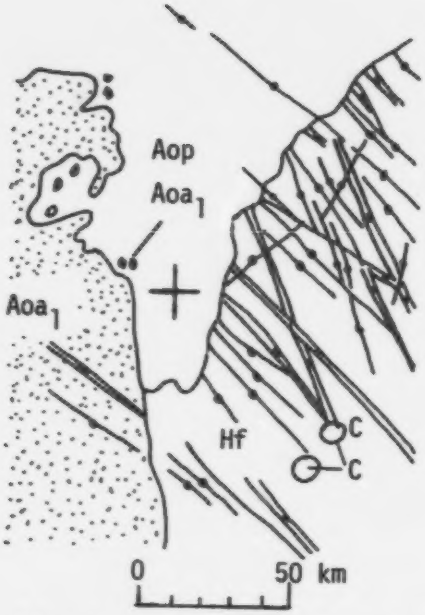
Aop
Aoa$_1$
Aoa$_1$
Hf
C
C
0
50 km

Fig. 1 Site #1 Tharsis-Olympus Region
Location: lat 12.5°N., long 125.5°

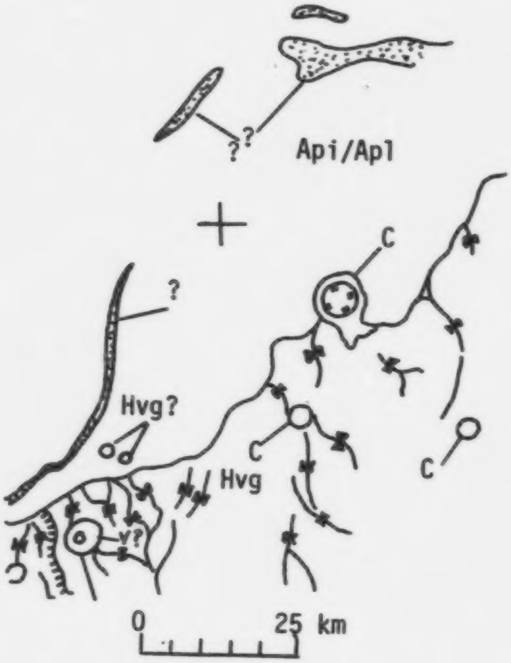
?
?
Api/Apl
?
C
Hvg?
C
Hvg
C
V?
0
25 km

Fig. 2 Site #2 Chasma Boreale
(North Polar) Region
Location: lat 82°N., long 57°

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MARTIAN SAMPLE SITES: EXAMPLES BASED ON A GLOBAL GEOLOGIC PERSPECTIVE;

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We have selected ten areas that each include several rock units of varying lithology and age (Table 1); these area were chosen to optimize the geologic and chronologic data return from Mars. Geologic mapping and stratigraphic studies [1-5] identify stratigraphic ages, rock types, and information on Martian geologic history that samples of a given site may yield (Table 2). Volcanic rocks occur over much of the planet and in virtually all stratigraphic positions, and they are amenable to radioisotopic dating. Therefore, a reasonable and essential goal for a sample-return mission is to return datable rocks from widely varying strata.

Generally, about three or four major geologic units can be sampled at any of the sites in Table 1, most of which can probably be dated (Table 2). The Mars Observer mission will aid greatly in interpreting lithology and defining contacts at the high resolution required to actually pinpoint fruitful sample-acquisition sites within these areas.

Table 1. Locations and Rock Units of Proposed Sample Areas

Site No.	Name	Location (lat, long)	Rock Units
1	Tharsis-Olympus	12°, 125°	Aop, flows of Olympus plains
			Aoa$_1$, lowermost aureole of Olympus Mons
			Hf, fractured flows of Ulysses Fossae
2	Chasma Boreale	82°, 57°	Apl, polar layered material
			Hvg, grooved plains material
			c, crater material
			unmapped, thick deposit
3	Memnonia	-10°, 172°	Amm, middle member of Medusae Fossae Fm
			Hr, ridged plains material
			Nplh, hilly unit of plateau sequence
4	Labeatis north	31°, 83°	Ht$_2$, member 2 of Tharsis Montes Fm
			Hr, ridged plains material
			Nf, highly deformed (faulted) material
5	Labeatis south	24°, 80°	At$_4$, member 4 of Tharsis Montes Fm
			Ht$_2$, member 2 of Tharsis Montes Fm
			Hr, ridged plains material
6	Solis	-27°, 100°	Hsl, lower member of Syria Planum Fm
			Hf, older fractured flows
			Nb, basement material
7	Hadriaca	-29°, 269°	Hhp, shield material of Hadriaca Patera
			Hpl$_3$, smooth unit of plateau sequence
			Hr, ridged plains material
			Nm, mountains of Hellas rim material
8	Elysium	27°, 185°	Ael$_1$, plains flows of Elysium Mons
			Hr, ridged plains material
			HNu, knobby remnants of plateau materials

9	Amazonis	22°, 165°	Aa_3, flows of Amazonis Planitia Hr, ridged plains material HNu, knobby remnants of plateau materials
10	Promethei	-81°, 315°	Apl, polar layered terrain Hdu, upper flows of Dorsa Argentea c, rim material of south polar basin

Note: Sites 1 and 2 described in [6]; geologic units described in [1-3]

Table 2. Stratigraphic Positions, Lithologies, and Ages of Geologic Events at Proposed Sample Sites

Objective	Sites									
	1	2	3	4	5	6	7	8	9	10
a. Stratigraphic position										
Upper Amazonian	L	R*								R*
Middle Amazonian			R*						R	
Lower Amazonian	L				R			R		
Upper Hesperian	R	R*		R	R	R				R
Lower Hesperian			G	G	G	L	L,G	G	G	
Upper Noachian										
Middle Noachian				G				G	G	
Lower Noachian			G			G	R			R
Poorly defined or uncertain		L*								
b. Lithologies										
Lava flows	X		X	X	X	X	X	X	X	X
Polar layered material		X								X
Olympus Mons aureoles	X									
Impact crater material		X								X
Other materials		X	X			X	X	X	X	
c. Ages of geologic events										
Channeling					X					
Tectonism	X			X	X	X				
Impact		X				X				X

Note: Extent of units to be sampled at individual sites indicated by G=global, R=regional, and L=local; asterisk indicates that unit may be undatable. Stratigraphic positions defined by [4, 5].

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SAMPLING STRATEGIES ON MARS: REMOTE AND NOT-SO-REMOTE OBSERVATIONS FROM A SURFACE ROVER

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I. Introduction

The mobility and speed of a semi-autonomous Mars rover are of necessity limited by the need to "think" and stay out of trouble. This consideration makes it essential that the rover's travels be carefully directed to likely targets of interest for sampling and *in-situ* study. Short range remote sensing conducted from the rover, based on existing technology, can provide significant information about the chemistry and mineralogy of surrounding rocks and soils in support of sampling efforts. These observations are of course of direct scientific importance as well. Because of the small number of samples actually to be returned to Earth, it is also important that candidate samples be analyzed aboard the rover so that diversity can be maximized. It is essential to perform certain types of analyses, such as those involving volatiles, prior to the thermal and physical shocks of the return trip to Earth. Additionally, whatever measurements can be made of non-returned samples will be important to enlarge the context of the detailed analyses to be performed later on the few samples which are returned. Some considerations related to these objectives are discussed below, and will be discussed in greater detail at the workshop.

II. Logistical Considerations

Considerable thought has gone into the technical issues of robotics and "artificial intelligence" which will be required to safely and efficiently rove the martian surface and collect samples. Much more work is needed to solve these complex problems, but it seems reasonable that stereo imaging, laser (or other) ranging, very significant computing power, and long stretches of time will be necessary. It is the responsibility of the Mars science community to ensure that science requirements are not totally subjugated to these engineering requirements. To a large degree the science and engineering tasks should be complementary. It is possible that some sensors, such as imaging, could be shared by the engineering and science subsystems. It is almost certainly necessary, however, that most of the science measurement and analysis instrumentation, including a powerful dedicated computer, be largely autonomous of the rover proper. This way useful scientific work, including compositional identification of potential samples, can proceed while the rover is working on logistical problems.

III. Remote Observations

Remote visible and near-IR spectral observations of the neighborhood immediately surrounding the rover can provide very significant mineralogic information about ferrous and ferric iron, OH and H_2O, and carbonates and other salts. Viking lander multispectral data have shown the basic utility of near-field compositional discrimination. These same data have proven the total inadequacy of conventional multispectral imaging for determining any detailed chemical or mineralogic information. It is therefore vital that complete, high-resolution spectra be obtained from the near-UV to about 5μm wavelength. The ideal situation would be to have a complete imaging spectrometer operating as a line-scan camera; this is expensive in many respects, though. Adequate information for directing sampling activities might be provided with lesser resources by a clever combination of multispectral imaging and spot spectrometry. Other compositional remote-sensing techniques, such as thermal infrared emission spectroscopy, have the potential to add valuable information, but are not as well-suited as reflectance spectroscopy to be the primary technique.

While absolute calibration of remote spectral observations is desirable, and probably feasible, it need not be perfect as long as complete spectra are obtained. Information which can be derived from spectral features in mafic materials, for example, includes determination of glass vs. crystalline basalt, pyroxene types and approximate compositions, the presence of olivine (if fairly abundant), and information about oxidation state. This information is often available in the near-infrared even when thin coatings of dust homogenize reflectance signatures at shorter wavelengths. What will certainly be required is major processing capability and "knowledge" onboard the rover. Early in the mission it is likely that most spectral analysis will be performed interactively by scientists on the ground. As instrument performance, calibration procedures, and spectral variety on Mars become better known, however, this information should be "taught" to the rover so that it can take over a large share of spectral processing and compositional characterization. Many of the basic analysis algorithms now exist or are currently being developed. They will need to be combined, though, in a sophisticated package utilizing aspects of artificial intelligence.

IV. Non-Remote Observations

Some level of analysis or verification of samples aboard the rover is essential prior to committing them to return to Earth. Desirable samples will vary in grain size from fine dust to pieces of rock, requiring versatility in sample collection and handling. Chemistry, mineralogy, and volatile content are all important to characterize, both for the samples chosen for return to Earth and for those discarded. An instrument similar to the Viking Lander X-ray fluorescence spectrometer might suffice for chemical determinations, although it would be desirable to have some additional capabilities. "Laboratory" spectroscopy of samples would provide confirmation of targeting criteria used for sample acquisition, as well as higher quality mineralogic and chemical characterization than available from remote observations. Additionally, diagnostic information about sensitive phases, especially volatiles, would be spectrally measured prior to the disruptive return flight. An important and complementary instrument is the combination of differential scanning calorimeter (DSC) and evolved gas analyzer (EGA), which would provide detailed quantitative information about volatiles and mineralogy. On a more speculative note, microscopic multispectral imaging could prove very useful for characterizing rock samples especially, although lack of uniform sample surface preparation might cause significant technical challenges.

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SOIL MICROSTRUCTURE AND ELECTRON MICROSCOPY

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As part of the process of comparing Martian soils with terrestial soils, high resolution electron microscopy and associated techniques should be used to examine the finer soil particles, and various techniques of electron and optical microscopy should be used to examine the undisturbed structure of Martian soils.

Speculation regarding the optical microstructure of the fine-grained portions of Martian soils ranges ranges from: (a) erde-structure, i.e. very small sub-spherical grains with both inter- and intra-crumb voids (residual from a previous climate); (b) salt-dominated (as in terrestial evaporite sediments); (c) freze-thaw-dominated; to (d) remoulded (by meteorites). Sections 30 μm ground from undisturbed blocks of impregnated material would help to differentiate between these hypotheses, reveal signs of illuviction or other unsuspected proceses, permit conventional optical mineralogy on the larger grains, and provide comparisons with terrestial soils. Little mechanical disturbance could be tolerated, and terrestial trials of the sampling gear would be needed. Temperature, pressure, and radiation would be less important. Use of a hard resin for impregnation (rather than Carbowax) would yield sections which could be passed from laboratory to laboratory and retained in museum conditions for a reasonably long life. Two sizes of sections are preferred: on slides 26 mm x 45 mm for universal stages; and samples say 25 mm x 50 mm upwards for an overview.

Supplementary observations using stereo-microscopy (and perhaps multi-spectral scanning optical microscopy) should be made on air-dry material. Mechanical disturbance is slightly less important and high temperature more important than for thin-sections. A microscope could be sent to Mars; but this non-destructive technique should be used to monitor other techniques on Earth.

A full series of micro-spectro-photometric analyses from ultra-violet to infra-red would support remote sensing. Disturbed material seems permissable; but the effects of heating and de- and re-hydration would be important.

Observation and classification of fracture surfaces of dry samples in scanning (reflection) electron microscopes is a well developed technique, which informs about both genesis and properties (6,7). Sampling requirements are somewhat similar to stereo-microscopy.

To examine the structure of fine-grained portions of the soil, transmission electron microscopy may be required. In the past, ultra-thin sections have been cut in an ultra-microtome from impregnated material; but ion beam thinning often gives better results (7). Ultra-microtomy can use samples as small as 1 mm cube; but larger samples are preferable, and it may be necessary to discard 1 or 2 mm on all sides of the final block to avoid the disturbance caused by cuting this block. Ion beam thinning often starts from discs 3 mm dia overcored from thin sections 30 μm thick and yields one ultra-thin sectrion per disc. Sampling requirements are somewhat similar to thin-sectioning.

SOIL MICROSTRUCTURE AND ELECTRON MICROSCOPY

P.Smart and J.R.Fryer

A striking feature of many Martian soils is their red colour. Although the present-day Martian climate appears to be cold, this colour is reminiscent of terrestial tropical red clays. Their chemical contents are broadly similar (2); and their optical reflectance spectra are similar to those of amorphous Hawaiian soils (e.g. 4). It is important to examine the iron oxides and hydroxides (and clay particles) in Martian soils directly to study their nature (morphology, crystal structure, cation exchange properties), their modes of formation (mechanisms of crystal growth and of aggregation), and their interactions with each other and with the clay minerals with which they are associated. Iron (hydr)oxides 5 nm dia have been found in terrestial soils (5) and require specialised techniques of high resolution electron microscopy and electron diffraction (1,3). To examine the (hydr)oxides themselves, disturbed samples are adequate; but the temperature and humidity requirements may be severe.

Assuming the pores of the soil in situ to be almost full of almost completely frozen water, the simplest procedure would be to lower the temperature to freeze the rest of the water, and to do as much observation as possible at this low temperature. Use of a high temperature to sterilise the soil might change some of the iron (hydr)oxides and clay minerals, also it might be necessary to use freeze-drying to remove the water first. Alternatively, it might be possible to develop a method of super-critical drying which both removed the ice and water and sterilised the remaining material. Sterilisation by fixing with chemicals such as osmium tetroxide or glutaraldehyde should also be considered (7).

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N89-18357

FLUVIAL PROCESSES ON MARS: EROSION AND SEDIMENTATION;

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One of the most important discoveries of the Mariner 9 and Viking missions to Mars was widespread evidence for modification of the martian surface by the action of liquid water. From the standpoint of a Mars Rover/Sample Return mission, fluvial activity on Mars is important in two ways. First, channel formation has deeply eroded the martian crust, providing access to relatively undisturbed subsurface units. Second, much of the material eroded from channels may have been deposited in standing bodies of liquid water. The aqueous sediments that exist on Mars may preserve an excellent record of conditions when the planet was significantly warmer and wetter than it is at the present. In fact, there is probably a much better sedimentary record of the first billion years of martian history than there is of the first billion years of the Earth's history. This record may be read by locating and returning samples of ancient water-lain martian sediments.

The most striking fluvial erosion features on Mars are the outflow channels. These are most common in the equatorial regions of Mars, and are concentrated along the northern lowland/southern highland boundary. They generally arise from the highlands and debouch onto the lowland plains. The source regions usually show very complex topography that earns them the name chaotic terrain. The appearance of the chaotic terrain strongly suggests removal of subsurface material and widespread collapse of topography. The channels arise fully-born from these chaotic regions and may extend for many hundreds of kilometers. Although clearly the result of fluid flow, outflow channels bear only superficial similarity to terrestrial rivers. They are much more similar to the types of features formed by catastrophic floods on Earth. They were probably formed when subsurface fluid was released rapidly from a highly porous and permeable subsurface aquifer. Once released, the floods were apparently of sufficient size that they proceeded for enormous distances across the martian surface. They probably could have formed under the present climatic conditions. The density of impact craters superimposed on the outflow channels indicates that they date from fairly early in martian history.

A second type of channel apparently caused by flow of liquid water is the valley system. These are more similar to terrestrial drainage systems, consisting of narrow, often sinuous valleys with tributary systems. They are dissimilar to terrestrial stream systems in a number of ways, however, exhibiting irregular junction angles, high bifurcation ratios, and lack of stream competition for interfluves. They are more similar to terrestrial drainage systems formed by sapping, although formation by precipitation cannot be ruled out in a few cases. Valley systems are found in the ancient cratered highlands. The density of superimposed impact craters indicates that formation of valley systems was concentrated in the earliest part of martian history, probably more than 4 billion years ago. Because the fluid discharges implied by the valley systems are quite modest, it is unlikely that they could have formed under the present climatic conditions. They therefore provide evidence that the pressure and temperature of the atmosphere very early in Mars' history were higher than they are today. This more clement era apparently did not extend past the earliest part of martian history.

The sedimentary deposits of outflow channels are often difficult to identify. No obvious deposits such as deltaic accumulations are visible in Viking images. Instead, one merely observes the streamline and scour features characteristic of outflow channel erosion gradually giving way to to a fairly nondescript plain. Similarly obscure sedimentary sink relationships are found for catastrophic flood features on the Earth. Significant fractions of Mars' northern lowland plains may indeed consist of sediments eroded from outflow channels. These plains contain a variety of enigmatic features, some of which may be consistent with a sedimentary origin. For example, large-scale polygonal fracture patterns may have resulted from sediment dessication. However, the tentative idenfication of channel deposits on the northern plains is made primarily on the unsatisfying grounds of proximity to channel mouths, rather than on deposit morphology. There is somewhat more compelling evidence for deposition at some locations within the outflow channels that emanate from the eastern end of the Valles Marineris. In particular, areas of chaotic terrain in the upper reaches of Tiu and Simud Valles contain smooth interior deposits that may be sediments either generated locally or transported from still further upstream.

Another set of deposits that may be water-lain and that date approximately from the epoch of outflow channel formation are the layered deposits in the Valles Marineris. These deposits are widespread in the canyons, and exhibit fine rhythmic near-horizontal layering that is continuous over large areas. The deposits form erosional remnants that once may have covered larger areas of the valley floors. These remnants most commonly take the form of plateaus up to 5 km high with exposed layering on their steep faces. Individual layers range from ~ 70 to 300 m in thickness, and there may be finer layering below the resolution limit of Viking images. The layered deposits were emplaced during roughly the same period in which the Valles Marineris were enlarged by sapping, collapse, and weathering of the walls to form spur-and-gully topography. Further local canyon wall collapse and perhaps deep erosion of the deposits in some areas followed; the outflow channels emanating from the east end of the Valles Marineris may date from this epoch of erosion. The deposits predate the major episodes of landsliding in the canyons. One attractive hypothesis for the origin of these deposits is that they were laid down in large lakes that once occupied the Valles Marineris. The horizontality, lateral continuity, great thickness, and stratigraphic relationships of the layered deposits are consistent with deposition in standing bodies of water. Materials could have entered lakes by slumping from canyon walls, volcanic eruption on the canyon floor, or downward transport through an ice cover. However, there are other hypotheses that may also be consistent with the appearance of these deposits in Viking images. In particular, it is not possible to rule out with certainty the possibility that they are subaerial explosive volcanic deposits. These deposits are voluminous, well preserved, and well exposed, and should be considered an important possible target for a sample return. However, their identification as aqueous sediments must presently be considered equivocal.

From the standpoint of a Mars Rover/Sample Return mission, the problem with all of these possible water-lain sediments is their age, or rather the lack of it. All appear to date from the epoch of outflow channel formation. They postdate the early epoch of valley system formation, and hence probably postdate the warmest epoch of martian history. While a great deal of attention has been devoted to the morphologic details and climatological implications of valley systems, very little consideration has been given to their sediments. Within the ancient heavily cratered terrain, there are localized depressions that have acted as catchment basins for the water discharged from these valleys. They surely received sedimentary deposits of some sort. In a few instances, deposits can be identified within such depressions, often having a surface texture suggesting post-depositional freeze-thaw or subsidence. These materials may preserve the best record of the chemical and climatic environment on earliest Mars, and should also be considered important potential sites for returned samples.

N89-18358

MARS ORBITAL TETHERED SAMPLE RETURN: THE FEASIBILITY AND USES OF OBTAINING ENTRAINED PARTICULATES FROM THE ATMOSPHERE: S.A. Stern, Dept. of Astrophysical, Planetary, and Atmospheric Sciences and Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392

By employing technology developed for the Tethered Satellite Program, it appears feasible to obtain Martian dust samples from the atmosphere using an orbiting spacecraft.

If collected during an annual dust storm, such a sample would contain a global selection of wind-borne materials.

Atmospheric dust sampling is of importance to the study of Martian surface geochemistry, soil mechanics, atmospheric dynamics, and atmospheric and radiative transfer.

Tethered sample return offers two key advantages over a lander sample return: relative simplicity and low spacecraft weight. Calculations demonstrate that such a mission could be carried out using either a Titan 3/Centaur or Titan 4/Centaur launch vehicle. Tethered Sample Return obviates the need for (1) a heavy-lift booster, (2) the development of both landing and surface launch vehicles, and (3) the development of automated rendezvous and docking technology. Tether deployment systems and sample collection spacecraft are presently under development for earth orbital missions.

A Tethered Sample Return Mission could provide the U.S. an early and low-cost opportunity to obtain Martian material.

In another vein, the collection of atmospheric dust by a lander sample return mission is itself of scientific merit. By employing a mast and collection plate aboard a lander mission, it is possible to obtain dust from distant locations transported as entrained material in the local aeolian environment.

Because tethered sample return addresses different scientific questions than do "conventional" surface and core sampling, the application of such a payload to Mars would complement a simultaneous or future surface sampling missions. Because the tethered platform could also carry an atmospheric payload, the potential to accomplish in-situ aeronomy also exists.

N89-18359

EXPERIMENTAL SIMULATIONS OF OXIDIZING CONDITIONS AND ORGANIC DECOMPOSITION ON THE SURFACE OF MARS;

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One important scientific objective of a Mars Rover Sample Return mission will be to look for traces of life on Mars, both living and extinct. An instrument to search for organic carbon may be the simplest survey instrument that could screen prospective samples which are interesting from a biological point of view. However, the Viking GCMS experiment showed that there was no organic carbon at either of the Viking lander sites up to the detection threshold of the instrument. This result was especially surprising because the abundance of organic carbon was lower than what would be expected from carbonasceous meteorites impacting the surface (1). This result implies that organic compounds are actively degraded on Mars. In addition to the absence of organic compounds, the Viking biology experiments showed that the surface soils on Mars were highly oxidized and chemically reactive. The results suggested that hydrogen peroxide, metal oxides, and/or superoxides were present in the Martian soil (1). The mechanism responsible for degrading organic compounds on Mars is undoubtedly related to the large flux of ultraviolet light on the Martian surface combined with the presence of strong oxidants in the soil (2). Before designing a sampling strategy to search for organic compounds on Mars, it will be important to understand the mechanism responsible for this degradation.

This paper describes an experimental program to understand the nature of the oxidizing soil on Mars and the mechanism responsible for organic degradation on the Martian surface. We are approaching this problem by performing laboratory simulation of the actual conditions that occur on Mars, particularly the production of oxidants by atmospheric photochemistry, and the combined effects of ultraviolet light and oxidants in decomposing organic compounds. Samples of Mars-analogue soils are placed in a chamber along with a Mars-composition atmosphere and irradiated with ultraviolet light. Organic decomposition is studied by mixing simple organics with the soils and analyzing the residuals after exposure to simulated Mars conditions. Experimental parameters such as soil type, water vapor content, and sampling depth are varied from chamber to chamber. Soil and gas composition is sampled periodically via Gas Chromatograph/ Mass Spectrometry. The results of these experiments will be used to formulate models of the photochemistry of the atmosphere, the atmosphere-soil interaction, and the diffusion of reactive compounds into the soil. This information will help provide insights and constraints on the design of a sampling strategy to search for organic compounds on Mars.

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N89-18360

NOBLE GASES AS TRACERS OF THE ORIGIN AND EVOLUTION OF THE MARTIAN ATMOSPHERE AND THE DEGASSING HISTORY OF THE PLANET; T. D. Swindle, Lunar and Planetary Laboratory and Department of Planetary Sciences, University of Arizona, Tucson, AZ 85710.

Noble gas analysis of Martian samples can provide answers to a number of crucial questions. Some of the most obvious benefits will be in Martian chronology, using techniques that have been applied with success to lunar samples (^{40}Ar-^{39}Ar ages and galactic cosmic ray exposure ages). However, these are by no means the only relevant noble gas studies possible. Since Mars has a substantial atmosphere, we can use noble gases to study the origin and evolution of that atmosphere, including the degassing history of the planet. This type of study can provide constraints on 1) the total noble gas inventory of the planet, 2) the number of noble gas reservoirs existing (related to the structure of Mars' interior), and 3) the exchange of gases between these reservoirs (related to the dynamics of the interior).

Comparison of terrestrial and SNC data

On Earth, there are at least two isotopically distinct noble gas reservoirs, the atmosphere (and most crustal rocks) and the source region of Mid-Ocean Ridge Basalts (MORB). The major distinction is that MORB noble gases are more radiogenic, i.e., are enriched in the decay products of the radioactive species ^{129}I (^{129}Xe) and ^{40}K (^{40}Ar). This suggests that the MORB source region (presumably the upper mantle) has been extensively degassed while a significant amount of ^{129}I (with a 16 m.y. halflife) was still present, which would require an intense early outgassing [1]. There are also suggestions that some hot spots (e.g., Loihi Seamount) contain noble gases from a third component, isotopically similar to the atmosphere (except for He and small differences in Ar), and postulated to represent the undegassed lower mantle [1].

Data from SNC meteorites suggest that the relationship of the various noble gas reservoirs on their parent body is different from that on the Earth. The gases in the Martian atmosphere (and the glass in EETA 79001) are far more radiogenic than the terrestrial atmosphere. However, Chassigny contains Xe that is less radiogenic than either the terrestrial atmosphere or the gas in EETA 79001 glass [2]. And stepwise heating experiments on EETA 79001 glass usually yield at least one extraction with Ar that is less radiogenic than the Martian atmosphere or any terrestrial samples [3]. Thus, if the SNC meteorites are from Mars, Mars must also contain at least two noble gas components, with the atmosphere as the more radiogenic reservoir. It is difficult, but not impossible, to explain the occurrence of an atmosphere less radiogenic than the interior. One possibility is a volatile-rich veneer [4], another is preferential extraction of radiogenic noble gases or their precursors, perhaps as a result of differentiation [5]. In addition, the nakhlites contain gas that isotopically resembles a mixture of Chassigny and Martian atmosphere, at least at Xe [6]. This is difficult to explain as an actual mixture, both because of the relative elemental abundances [2] and because Mars, with its thinner atmosphere and lack of liquid water or plate tectonics, would not seem as likely as the Earth to have atmospheric noble gases available to mix with interior gases at any great depth. Clearly, we need a better understanding of the number, composition and location of Martian noble gas reservoirs.

Samples that would be useful

The first sample that would be necessary for this sort of work would be a sample of the Martian atmosphere, both for modeling and also to verify that the gas in EETA 79001 glass is really Martian atmosphere. Although it is possible that such analyses could be made with suitable precision in previous (non-sample return) missions, the amount of atmosphere required is not large. One cubic centimeter of Martian atmosphere at ambient (Martian surface) pressure contains an amount of noble gas comparable to that in a typical calibration run. Thus one liter would contain enough gas for duplicate analyses of the noble gases and other atmospheric species of interest.

To sample the interior of Mars, the ideal sample would be a fresh, quickly chilled lava (like the glassy margins on terrestrial MORB samples) or a xenolith in a mantle-derived lava (like the Hawaiian volcanoes). We may not be likely to find a truly pristine Martian sample, but we should look for the freshest basalt we can find, presumably from some of the youngest areas on Mars. Since Chassigny (age 1.3 Ga) contains a substantial amount of non-atmospheric noble gases, we have a reasonable chance of finding an appropriate sample. Conveniently, Olympus Mons and the other shield volcanoes in the Tharsis region have some of youngest terrain on Mars and a deep (mantle?) source region (7). Thus, the best samples for this study would probably be rocks (not soil) from the flanks of Olympus Mons and/or other volcanoes in the Tharsis region.

It is also possible that, unlike the terrestrial situation, crustal noble gases may be isotopically distinct from those of the atmosphere. This might be determined from a soil sample from almost any site.

Finally, we might be able to set a limit on the degassing rate of Mars (and/or the rate of loss of atmospheric gas) by finding paleoatmospheric samples. On Mars, samples that might have been in equilibrium with the atmosphere at some time in the past include the proposed buried carbonates or water-deposited sedimentary rocks. It might be difficult to find either of these, although some sediments in Valles Marineris and in the ancient cratered terrain may be the result of water deposition (8). Also, the presence of gas similar to the Martian atmosphere in the shock glass in EETA 79001 suggests that shock could implant the ambient atmosphere into a sample. Thus, we might also get a sample of paleoatmosphere from shock glass from a returned sample associated with a crater of known, preferably old, age. Note that the time of the shock event that produced the glass in EETA 79001 is a matter of debate, but is probably within the last 200 Ma.

Rock and soil samples would probably need to be 0.1 to 1.0 grams for high-precision analysis with present-day equipment. The best samples would be ones that had never been exposed to galactic cosmic rays, which would require a burial depth of at least one meter. Samples with detectable galactic cosmic ray spallation products might still be useful, but the present limit on the amount of information we can extract from SNC meteorites is largely determined by their cosmic ray exposure history.

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N89-18361

EXAMINATION OF MARTIAN SEDIMENTARY ROCKS TO UNDERSTAND POSSIBLE PALEO-OCEAN AND ITS AGE;

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It is known well that the terrestrial marine sediments have large cerium anomaly on their chondrite-normalized REE pattern. Siliceous shale and calcaleous sediments have negative Ce-anomaly. Ferromanganese nodule has positive or negative Ce-anomaly. The Ce-anomaly is considered to be a result of tetravalent state of cerium rather than common trivalent. Ferromanganese nodule which formed under reducing condition has negative Ce-anomaly. Then, combined study of Ce-anomaly with Ce isotopes is expected to play an important role in geochemistry.

^{138}La decays to ^{138}Ce and ^{138}Ba with a total half-life of about 1×10^{11}yr. La-Ce decay schem is used successfully as a geochronometer (1)(2). The La-Ce isotope system also has potential as an isotope tracer (3)(4)(5). Crustal rocks have $+\epsilon_{Ce}$ and $-\epsilon_{Nd}$ values whereas MORB and IAB have $-\epsilon_{Ce}$ and $+\epsilon_{Nd}$ value. Pacific ferromanganese nodules have positive and negative Ce-anomaly. All of the examined nodules have $-\epsilon_{Ce}$ and $-\epsilon_{Nd}$ value (Fig. 1) (6). This suggest that cerium in ferromanganese nodules dominantly originated from abyssal volcanics, while neodymium originated from continent.

Cerium anomalies (positive or negative) are expected in Martian paleo-ocean and in sediments as observed in the terrestrial environment. The followings could be examined.

1) La-Ce age of the sediments. This age will indicate the formation age of Ce-anomaly. When some evidence of paleo-life (fossil) is found in the sediments, La-Ce age indicates the age of life (=sedimentation). Large Ce-anomaly in sediments will make age determination easy.

2) Initial ^{138}Ce/^{142} Ce ratio will represent local ^{138}Ce/^{142} Ce ratio in marine environment.

3) Isotopes of Neodymium, Strontium, Lead, Hafnium will be examined systematically using a same solution.

4) Variation (positive or negative) of Ce-anomaly gives an information of oxidation-reduction state of marine environment.

Igneous rock seems rather common in the solar system, but sedimentary rock only be expected in Mars. My interest is in aquaous situation and life (fossil?).

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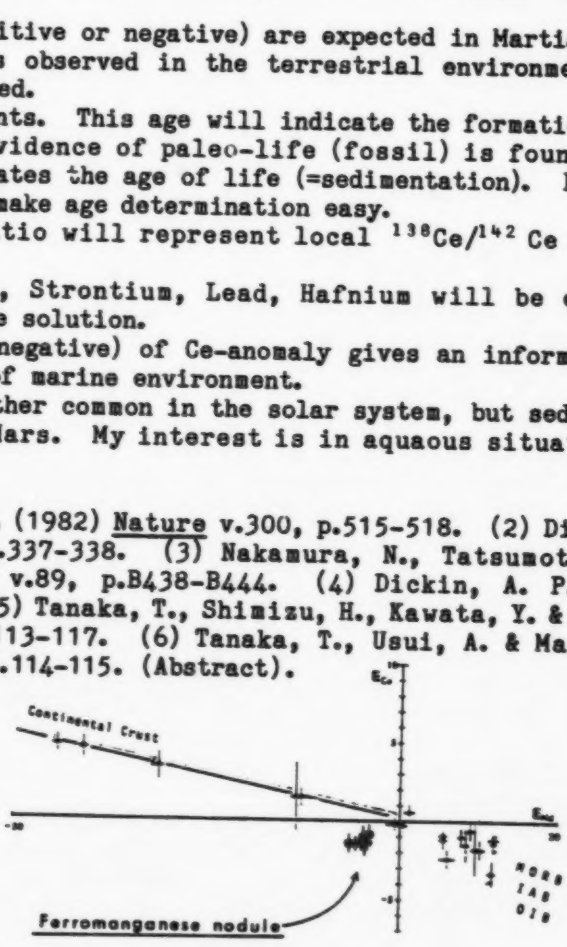

Fig. 1
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N89-18362

U-Th-Pb, Sm-Nd, Rb-Sr, and Lu-Hf Systematics of Returned Mars Samples.

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As Drake et al. [1] emphasized, the advantage of studying returned planetary samples instead of accepting in situ measurements cannot be overstated. A wider range of state-of-the-art analytical techniques with higher sensitivities and accuracies can be applied to returned samples. Measurements of U-Th-Pb, Sm-Nd, Rb-Sr, and Lu-Hf isotopic systematics for chronology and isotopic tracer studies of planetary specimens cannot be done in situ with desirable precision.

Returned Mars samples will be examined using all the physical, chemical, and geologic methods necessary to gain information on the origin and evolution of Mars. Drake et al. [1] evaluated oxygen isotopes, noble gases, and siderophile trace-element abundances for constraining theories regarding the origin of the solar system and the assembly of the planets. We argue that the radiometric systems listed above, especially U-Th-Pb, can also provide some vital data on the evolutionary history of the planetary body. Because the U-Th-Pb system includes three decay schemes, two of which involve U-Pb, it can provide insight into a rock's history prior to crystallization by using a concordia plotting method [2]. Our group has suggested that the Nakhla meteorite may have originated from a large planetary body, possibly from Mars, based on U-Th-Pb, Sm-Nd, and REE abundances (Nakamura et al., [3]). Some other studies of SCN meteorites (e.g., Bogard and Johnson, [4]; McSween, [5]) have also suggested the same idea. A Martian origin for the SNC meteorites is now generally conceded based on recent detailed studies of the Shergotty meteorite (Laul et al. [6] and references therein).

SNC meteorites have distinctly low ^{206}Pb/^{204}Pb values, between 12 and 15 (Nakamura et al., [3]; Chen and Wasserburg, [7]), whereas those for the Earth and the Moon are 18-20 and 150-500, respectively (Fig. 1). These values indicate that the SNC meteorites evolved in a unique environment with a low ^{238}U/^{204}Pb (μ) = 5 during the history of the solar system. This μ value is distinctly lower than that for the Earth (8±2), the Moon (20--300), and eucrites (100-150), implying that the SNC parent planetary body was rich in volatile elements compared to the Earth. If SNC meteorites do come from Mars, then Mars must be enriched in volatile elements. The volatile-rich Mars interpretation, however, contradicts the contention of Anders and Owen [8] that Mars is intrinsically poorer in volatiles compared to the Earth [7]. Because lead is a chalcophile element, which could be removed to the Martian core as is often inferred from terrestrial basalts (the Earth's Pb "paradox"), either the smaller core of Mars may have been less effective in the removal of Martian Pb, as Chen and Wasserburg [7] have suggested, or core differentiation was delayed on Mars (2.7-3.6 b.y., [9] compared to ~4.3 b.y. for the Earth [10]; however, only Nakhla data suggest this). Detailed Pb isotopic analyses of Martian samples would provide a unique opportunity to investigate this problem, as well as to obtain chronological information.

Analytical techniques used in the study of U-Th-Pb, Sm-Nd, and Rb-Sr systematics have been improved tremendously during Apollo sample investigations. Expecting future improvements (such as an ion microprobe [11], analysis of three systematics using only a few hundredths of a gram or less of a returned Martian sample (the study of Lu-Hf systematics requires, at present, larger sample sizes compared to the other three systems) would provide ample information regarding the accretionary and evolutionary history of the Martian planetary body and possibly other planets of our solar system.

If the Mars samples are collected by deploying a rover vehicle for the lander's 401-day stay, a wide variety of rocks, soils, and other materials will be collected [1]. For chronological purposes, igneous rocks are of particular interest to us. We think that the volcanic Tharsis region has the greatest potential as a landing site. Not only would the numerous documented flows of the Tharsis Montes provide sampling of young and intermediate-age volcanics, but the adjacent Syria Planum may possibly provide a chance at much older rocks exposed in the prominent fractures of Noctis Labyrinthus [12].

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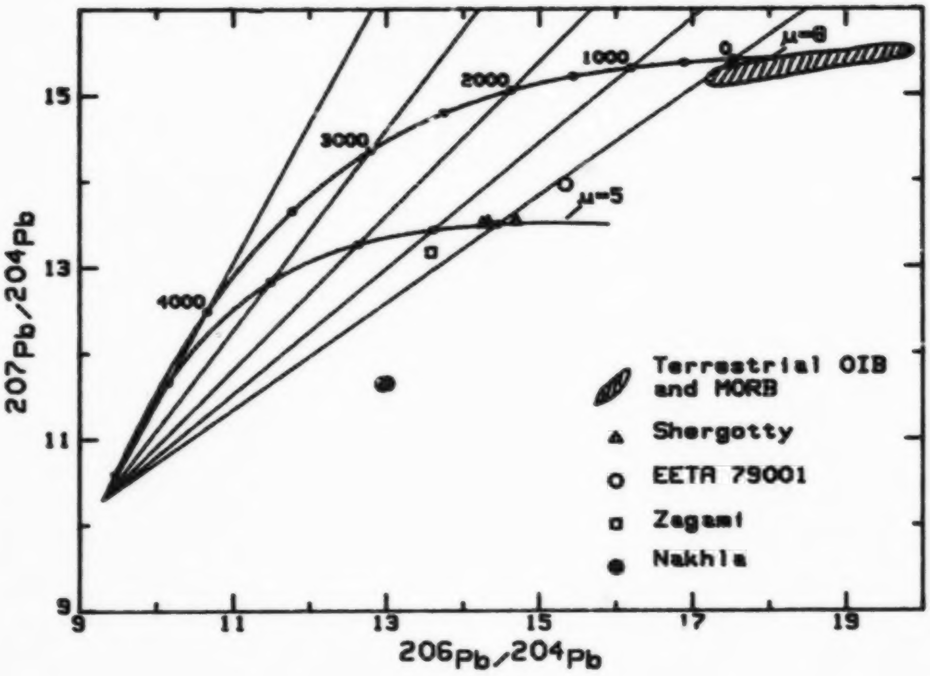

Fig. 1 $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagram for SNC meteorites and terrestrial oceanic basalts. The Pb growth curves having a primordial Pb (Cañon Diablo troilite Pb) at 4.56 Ga ago and present-day μ values of 5 and 8 are shown. SNC meteorite data plotted by open symbols are from [7], and Nakhla data plotted by solid circles are from [3].

EARTH-BASED RADAR CONTRIBUTION TO MARS SAMPLE RETURN; T. W. Thompson and L. Roth, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Earth-based radar has often observed planets decades before space missions and provided valuable information leading to the success of those missions. As we contemplate how a Mars Sample Return Mission will be performed, we should review possible measurements by earth-based radars.

The most direct radar measurement is ranging where echo time provides topography. This is a good experiment for Mars as the rapid rotation provides surface coverage of several tens of degrees of longitude in a few hours of observation. A second radar measurement is total echo power which, in turn provides estimates of the bulk dielectric constant of the surface. Mars shows a large variation in this quantity. A third radar measurement is the echo shape which can be related to rms slope of the surface. A fourth radar measurement involves diffuse scattering which is controlled by the populations of wavelength-sized rocks.

Another important factor in earth-based radar observations of Mars is the interplay between the orbits of Mars and earth and the fact that radar echo strength is proportional to the inverse fourth power of the Earth-Mars distance. Observations of Mars are done near opposition when the Earth-Mars distance is less than 1.0 AU. Furthermore, the oppositions near perihelion have ten time stronger echoes than oppositions near aphelion. The 1986, 1988, 1990 oppositions are near perihelion and are the best times to observe Mars since 1971-1973 and until 2001-2003-2003.

Earth-based radar coverages in 1986, 1988, 1990 complement the 1971-1973 observations and cover Mars latitudes from the equator to -25^{o} (about 20% of the martian surface). Radar observations for the remainder of the 1990's will be north of the equator covering latitudes from the equator to 25^{o}. Futhermore, the proposed radar upgrades at the Arecibo radar facility will overcome some of the deficit in echo power mentioned above. A summary of earth-based radar echo strength and martian latitude coverage is shown in figure 1.

The ability of earth-based radars to measure topography is illustrated in Figure 2, which shows an elevation profile of crater Bakhuysen (344.0^{o} -23.0^{o}, 140km) in Sinus Sabaeus. The radar profile shows a raised rim and flat floor.

The ability of radars to measure dielectric constant is illustrated in Figure 3, which shows measurement from twenty six 12.5 cm tracks of the Goldstone Radar in 1986, when the latitude coverage was -3^{o} to -10^{o} (a new area for earth based radar). The bulk dielectric constant for longitudes of 180^{o} to 90^{o} is 3.0-4.0, while longitudes of 75^{o} to 0^{o} (Valles Marineris) have dielectric constants near 5.0. These dielectric constants are reasonable values for regoliths with the regoliths. Analysis of the 1971-1973 Goldstone 12.5 cm data suggests that Mars radar may be reflectivity related to martian seasons, as shown in Figure 4.

In summary, earth-based redars provide measurements of topography, bulk dielectric constants, rms slopes, and surface rock populations. All these measurements will be valuable to a Mars Sample Return Mission. The 1988 and 1990 oppositions provide excellent opportunities to extend southern earth-based coverage of Mars to -25^{o}, while oppositions for the rest of the 1990's will provide coverage of northern latitudes to 25^{o}.

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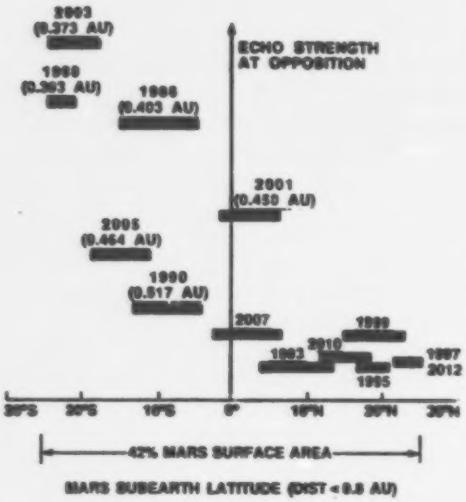
EARTH-BASED RADAR CONTRIBUTIONS TO MARS SAMPLE RETURN

T. W. Thompson and L. Roth



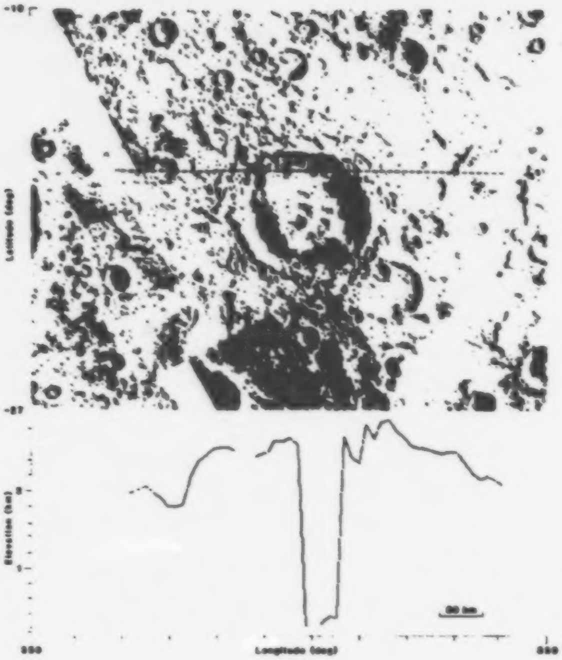

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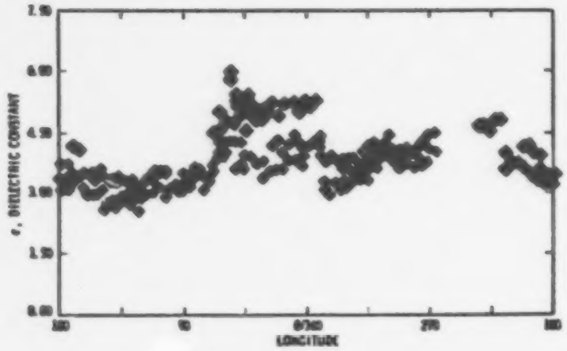
Fig. 1. Mars Echo Strength vs. Coverage   Fig. 2. Mars Radar Elevations



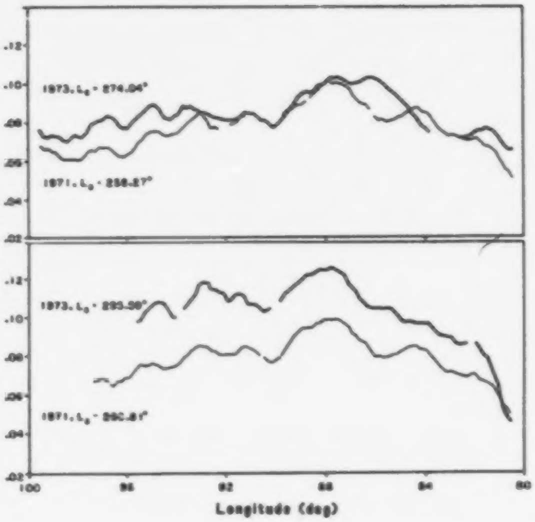


Fig. 3. Mars Dielectric Constants   Fig. 4. Mars Reflectivity vs Season

N89-18364

CRYSTAL FRACTIONATION IN THE SNC METEORITES: IMPLICATIONS FOR SAMPLE SELECTION

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Almost all rock types in the SNC meteorites are cumulates, products of magmatic differentiation by crystal fractionation (addition or removal of crystals). If the SNC meteorites are representative of rocks at or near Mars' surface, then the Mars Sample Return must include strategies for collecting from differentiated igneous bodies.

The SNC meteorites include ten lithologies (three in EETA79001), eight of which are crystal cumulates [1]. The other lithologies, EETA79001 A and B, are sub-ophitic basalts. The cumulate lithologies ALHA77005 and EETA79001C have not been fully described and are not discussed here.

Shergotty and Zagami

The Shergotty and Zagami meteorites, diabases or fine-grained gabbros, are enriched in clino- and ortho-pyroxene relative to their parental magmas [2]. It has been suggested that the pyroxene enrichments arose through crystal settling [3], but this is unlikely. The parent magmas were basaltic, and thus had significant yield strengths. If the parent magmas had yield strengths like those of terrestrial basalts [4], the stress generated by a pyroxene crystal would have been below the yield strength of the magma (e.g. [5]). The pyroxene would not move.

Another fractionation mechanism, crescumulation, is more likely for Shergotty and Zagami. Crescumulates form at moderate undercoolings when new crystals nucleate at the walls of a magma body and grow inwards as elongate blades. The blades continue to grow as the melt among them is replenished by exchange with the bulk magma. As the blades grow wider, melt among them is "squeezed out". Typical features of crescumulates are: mild to moderate enrichment in the blade minerals; grains with quench morphologies; grains longer (greater aspect ratios) than usual for the mineral species; and moderate lineations of the elongate minerals without strong foliation [6-8]. Examples of crescumulates include spinifex zones in komatiites [6], harrissite in ultrabasic intrusions [7], and "Willow Lake textured" rock in gabbros and basalts [8].

Shergotty and Zagami have most of the petrographic features of crescumulates. They are mildly enriched in pyroxenes relative to their parental magmas [2]; Shergotty is 28% and Zagami is 45% cumulus pyroxenes. Some whitlockite grains in Shergotty are very elongate and rich in inclusions [9], a typical quench morphology. Pyroxenes in Shergotty and Zagami are more elongate that typical basalt pyroxenes, which have aspect ratios <3; in Shergotty, aspect ratios range up to 7 or possibly 20 ([10], Fig. 1). The pyroxenes also show a preferred elongation direction [2, 10], which could be either a lineation, a foliation, or both.

Nakhlites and Chassigny

The nakhlites and Chassigny are ultramafic igneous rocks, rich in augite and olivine respectively. They are cumulates, strongly enriched in crystals relative to their parental ultrabasic magmas [11-12]. The nakhlites and Chassigny are inferred to have formed through settling of crystals [11-13]; this inference is surest for the nakhlites because their cumulus augites form a grain-supported framework, and because the augites have preferred orientations typical of sediments [13]. Non-Newtonian behavior of the magma is unimportant because ultrabasic magmas have low yield strengths (e.g. [14]).

Conclusions

Almost all of the SNC meteorite lithologies are products of crystal fractionation, and the likelihood of fractionation must be considered in choosing sample sites and individual samples. Based on the shergottites, a single sample taken from a basaltic igneous body may have experienced only moderate crystal fractionation and may be fairly representative of the whole body. Additional samples from the same body would be useful, but probably not essential. Based on the nakhlites and Chassigny, a single sample taken from an ultrabasic igneous body will have experienced extreme crystal fractionation and probably would not be representative of the whole body. Analogous bodies on Earth differentiated to yield peridotite, pyroxenite, and gabbros [15]. Multiple samples from ultrabasic igneous bodies would be essential in recovering the original magma compositions.

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SAMPLE SELECTION AND PRESERVATION TECHNIQUES FOR THE MARS SAMPLE RETURN MISSION;

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It is proposed that a miniaturized electron spin resonance (ESR) spectrometer can be developed as an effective, non-destructive sample selection and characterization instrument for the Mars-Rover-Sample Return mission. The ESR instrument can meet rover science payload requirements (5-10 Kg), and yet has the capability and versatility to perform the following in situ Martian sample analyses:

1. Detection of active oxygen species (superoxide O_2^-, peroxide $-O-O^-$, ozonide O_3^-, and hydroxy radical), and characterization of Martian surface chemistry and photocatalytic oxidation processes.
2. Determination of paramagnetic Fe^{3+} in clay/silicate minerals, Mn^{2+} in carbonates, and ferromagnetic centers of magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3) and hematite (α-Fe_2O_3).
3. Search for organic compounds in the form of free radicals in subsoil, and detection of Martian fossil organic matter likely to be associated with carbonate and other sedimentary deposits.

These analyses can be carried out on gram- to milligram-size Martian surface and subsurface samples; minimum or no sample preparation is required.

The presence of active oxygen species has been invoked in interpretations of the Viking biological experiments and a model has also been suggested for Martian surface chemistry[1,2]. In addition, photocatalytic oxidation processes involving these oxygen species has been suggested as the cause of the apparent non-detection of organic compounds in the Viking GCMS (gas chromatography-mass spectrometry) experiments[3,4]. At present, one knows very little about the destructive oxidation mechanisms operating on Mars. Since these oxygen species are all paramagnetic in nature, they can be readily detected in native form by ESR. Thus, a Rover ESR instrument should uniquely provide information on the oxidation/reduction conditions of Martian surface and subsurface samples, and on the detailed mechanisms of photo-oxidation processes if occurring on Mars. Such information may not be obtainable simply from returned sample analyses, in view of the reactivity and transient nature of these active species. Furthermore, these paramagnetic and ferromagnetic centers can be used as probes to define the physical and chemical properties of Martian samples in terms of their surface oxidant content. We can also perform ESR studies on the distribution of paramagnetic and ferromagnetic centers as a function of the depth from the Martian surface. This will help to define the nature of Martian surface layers and the regolith depth, formation conditions and processes; and thus to define criteria in the selection of samples for the return mission. The ESR data such as concentration, reactivity and thermal stability for the active oxygen species generated under simulated Martian conditions can be used to develop sample preservation techniques. The ESR experiments are needed in the screening of sample container materials as well as in the design of procedures required for sample handling, storage and preservation during the trip to Earth in the return mission.

The proposed ESR experiments are based on the unique ESR signals characteristic of organic free radicals, Mn^{2+} in calcite (Fig. 1), superparamagnetism of ferromagnetic centers[5], O_2^- and $-0-0^-$ (Fig. 2). A lightweight magnet for the proposed miniaturized ESR instrument has been developed at JPL[6]. Magnetic susceptibility measurements as well as simple magnetic separation can be performed using this already developed miniature magnet assembly.

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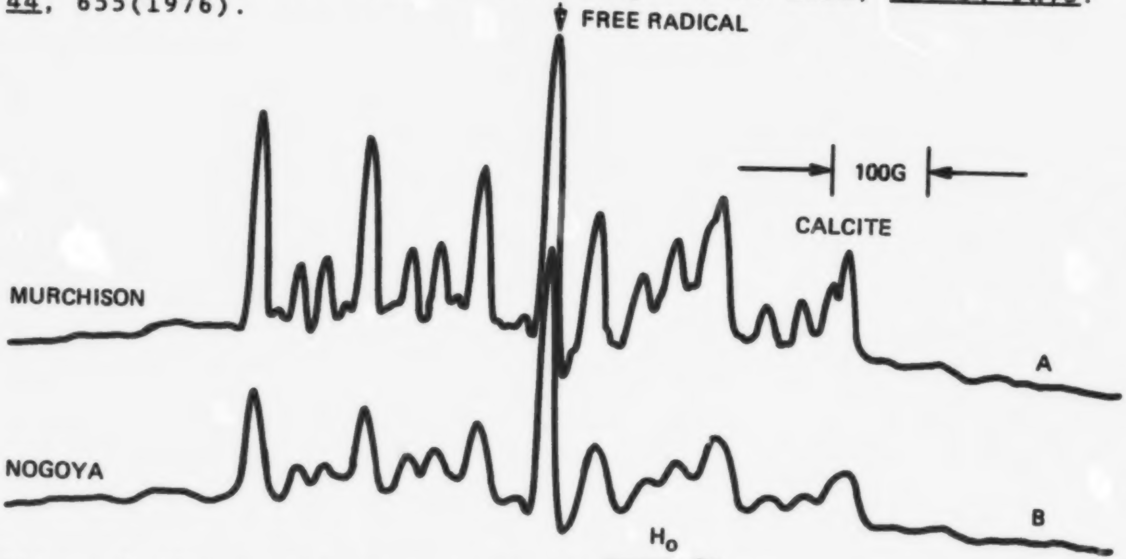

Figure 1. Second-derivative ESR signals attributable to organic free radicals and Mn^{2+} in calcite observed in CM2 chondrites.

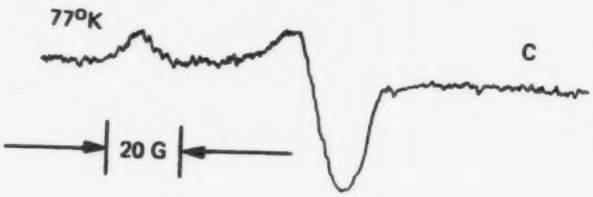

Figure 2. First-derivative ESR signals of peroxy radicals ($-0-0^-$) observed in a polymer at 77°K.

N89-18366

OVERVIEW OF MARS: SNC METEORITE RESULTS,

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The SNC meteorites according to their oxygen isotope ratios (1) and various trace element ratios (2-3) form a distinct group of 8 achondrites. Their young crystallization ages and fractionated REE pattern which exclude an asteroidal origin, were the first observations to point towards Mars as their parent body (4-6). Further evidences came from the discovery of a trapped rare gas and nitrogen component with element and isotope ratios closely matching the highly characteristic ratios of the Mars' atmosphere (e.g. $^{40}Ar/^{36}Ar$; $^{14}N/^{15}N$; $^{14}N/^{40}Ar$ and $^{129}Xe/^{132}Xe$) in shock glasses of shergottite EETA 79001 (7-9). Jagoutz and Wänke (10) obtained for Shergotty a Sm/Nd age of 360±16 myr. The 180±20 myr Rb-Sr age found in shergottites had been interpreted as shock age (11-12), as true crystallization age (13) and as thermal spike due to by endogenic process (10). Recent work on ALHA 77005 (14) yielded a crystallization age of 154±6 myr and a shock age of 15±15 myr, which agrees with the cosmic ray exposure age of 2.7 x 10^6yrs (15) and, hence, obviously dates the ejection of this meteorite from its parent body. Jochum and Palme (16) observed that the range of variation of the Zr/Nb respectively Hf/Ta ratios for the SNC's is intermediate between that of the Earth and the Moon (Fig. 1). In spite of the numerous arguments for Mars as the parent body of the SNC meteorites there does not exist a generally accepted model for the ejecting process and other dynamical problems involved (17). In the following discussion it is, however, assumed that Mars is indeed the SNC parent body.

Compared to the terrestrial mantle the higher FeO content of the shergottites reflects the higher FeO content of the Martian mantle, while the high MnO and Cr_2O_3 concentrations in shergottites indicates that it is not depleted in MnO and Cr_2O_3. Similarly, phosphorus is much more abundant. Aside pressure effects and the H_2O poverty, the high P content of the Martian mantle could be of influence to magmatic processes. A low degree of fractionation and a large proportion of Mg-rich provinces seem to be further important characteristics of the Martian crust.

On the Earth, the Moon and the eucrite parent body the refractory lithophile elements and Si and Mg are present in these objects within ± 30% in C 1 abundances. The same holds for Fe if we neglect the Moon. The major differences in the compositions of planets lie in the Fe_{metal}/FeO-ratio in the concentrations of the moderately volatile and volatile elements and in the distribution of chalcophile and siderophile elements between mantle and core. With these assumptions and the use of a number of element correlations Dreibus and Wänke (18) calculated the composition of the Martian mantle (Table 1 and Fig. 2). Similar to the case of the Earth almost identical depletions for a number of geochemically very different elements are found for the Martian mantle. The mean abundance value for the elements Ga, Fe, Na, P, K, F and Rb in the Martian mantle is 0.35 and, hence, exceeds the terrestrial values by about a factor of two. The composition can successfully be explained in term of the two component model (19,20). According to this model the terrestrial planets are formed from a highly reduced component A almost free of all elements more volatile than Na and an oxidized component B containing all elements in C 1 abundances but with different mixing ratios. In the Martian mantle there are, however, a number of elements which relative to Fe, Na, Ga, K, F and Rb have either a higher abundance as in the case of W, or considerably lower abundances as in the case of Zn, Co, Ni, Cu and In. The latter elements all have rather strong chalcophile character. These depletions point

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towards homogeneous accretion. The high portion of component B which supplied large amounts of sulphur was obviously responsible that FeS became a major phase and at its segregation extracted all chalcophile elements according to their sulfide-silicate partition coefficients. These partition coefficients are low for W, Cr and Mn. The bulk composition of Mars (mantle+core, Table 1) is in excellent agreement with the geophysical data of the planet.

The SNC meteorites are extremely dry rocks. Shergotty contains 180 ppm H_2O which would indicate about 36 ppm H_2O for the Martian mantle. This is exactly the value obtained by comparing the solubilities of H_2O and HCl in basalts (21). The amount of ^{132}Xe in Shergotty (22) compared with the ^{132}Xe in the Martian atmosphere (23), yields an upper limit for the degassing efficiency of the Martian mantle of about 40%, while a lower limit of 2.6% can be obtained from the amount of ^{40}Ar released to the atmosphere. Assuming the degassing efficiency of H_2O to be within these limits, we obtain for the amounts of H_2O released to the surface values which would correspond to surface layers (ocean) of about 3.5 to 50m depth.

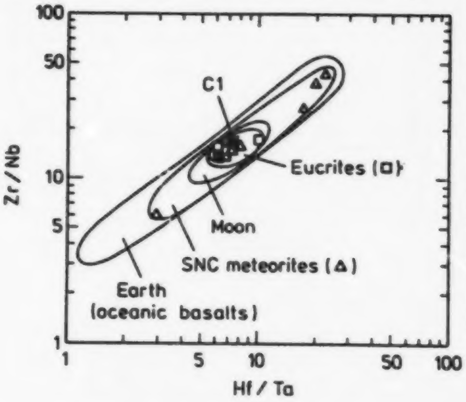

Fig.1 Fig.2

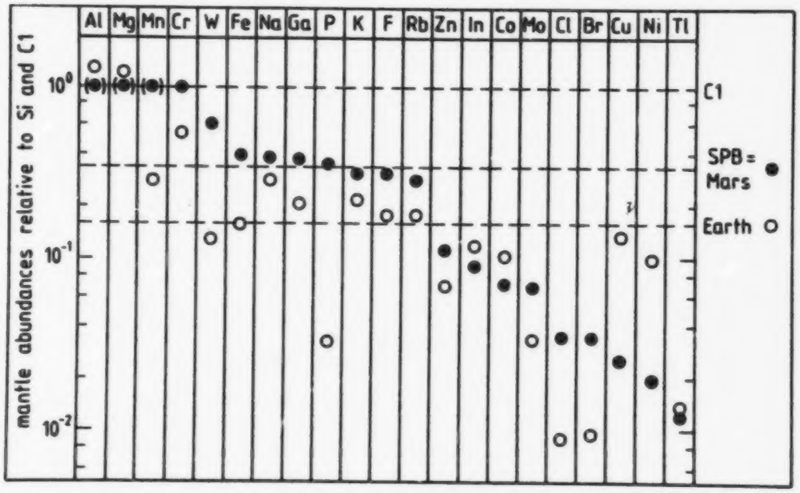

Table 1: MARS

Mantle + crust		
MgO	%	30.2
Al_2O_3		3.02
SiO_2		44.4
CaO		2.45
TiO_2		0.14
FeO		17.9
Na_2O		0.50
P_2O_5		0.16
Cr_2O_3		0.76
MnO		0.46
K	ppm	305
Rb		1.06
Cu		5.5
Zn		74
Ga		6.6
Mo	ppb	118
In		14
Tl		3.6
Cl	ppm	38
Br	ppb	145
I		32
La	ppm	0.48
Th	ppb	56
U		16
Core		
Fe	%	77.8
Ni		7.6
Co		0.36
S		14.24
Core mass %		21.7

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PROCESSING AND REDISTRIBUTION OF SURFACE AND SUBSURFACE SAMPLES BY IMPACT CRATERING;

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As a portion of the the martian surface becomes more densely cratered, the more the surface and subsurface materials become laterally redistributed and impact metamorphosed. This abstract characterizes specimen redistribution as a function of both impact density and original specimen depth, and also characterizes the impact histories of those specimens.

Method

An entirely new Monte Carlo simulation is being constructed along the lines of Cashore and Woronow (1985). It currently includes complex crater geometries (flat floor, inner rim, inward-sloping ejecta blanket, and exponentially decaying outward ejecta blanket) according to the parameters given by Pike and Davis (1985). Crater ejecta blankets extend to five radii from the crater center and conserve excavated volume. This simulation utilizes a variable-size, gridded target surface with an evolving topography interpolated between the grid points. For this study, the surface is 1500 km by 1500 km with 256 grid points.

Crater diameters are selected at random from the production distribution function defined by Woronow, et al. (1982) for craters greater than 8 km in diameter. Crater centers are located uniformly randomly on the surface at the instantaneous local elevation. A zone around this target surface can receive impacts and spray ejecta onto the target surface, but data are not retained on that extended zone.

Tracer particles (representing possible "grab samples") may be placed on the surface or embedded in the subsurface. When excavated by an impact, the tracers are "entrained" in both the ejecta and the in-crater fallback. Repeated trials record the number of impacts sustained by each tracer and the tracer's total displacement.

Results

This abstract reports only on those tracers that, at the termination of the simulation, resided in an ejecta blanket rather than in the crater fallback.

For tracers starting from the same depth, as the cumulative crater flux (measured in multiples of the observed lunar highlands density, OLHD) increases, tracers tend to be spread increasingly farther from their original sites and to experience an increasing number of excavation/redistribution events. However, the displacement distance is only weakly related to the total impact flux, the median displacement for 1x OLHD being about 70 km increasing to only about 90 km for 3x OLHD (Figures 1a,b). The most distantly displaced tracers are not necessarily the ones that experience the greatest number of impacts. This is apparently because large, relatively rare, events at any flux dominate the lateral transport of tracers. Small craters are relatively inefficient dispersers of tracers because 1) they may not excavate to the tracers buried in an ejecta blanket or subsurface, and 2) in a random walk process like this one, the expected displacement is proportional to D n where D is the average step size and n is the number of steps. Concentrating on the second of these, the first having a rather obvious effect, we note that D increases linearly with crater (and ejecta) size whereas n depends upon the number of craters of size D. For the assumed production function, if we select D_1 to be 500 km and D_2 to be 10 km then n_1/n_2 is approximately 1000. Therefore, the ratio of $D_1\ n_1/D_2\ n_2$ shows that a single 500 km diameter crater, on the average, disperses tracers about 1.5 times farther than the combined efforts of the 1000 corresponding 10 km diameter craters!

Figures 2a-d show the number of impacts experienced by tracers initialized at a variety of depths and sustaining various cumulative impact fluxes. In Figure 2a and b, the solitary effects of increasing flux may be seen. Fewer tracers avoid impacts, and the average number of impacts experienced increases from 0.6 to 2.6 for an increase in the flux from 1x to 3x OLHD. As the initial burial depth of the tracers is increased (Figures 2c,d), while maintaining a constant 3x OLHD, the distribution of the number of impacts suffered almost reverts to one like that for a lower flux (compare Figures 2c,d with Figure 2a). However, very important differences exist. First, for shallow burials (e.g. 2 km in Figure 2c), although many tracers escape excavation, once excavated they sustain a greater average number of impacts than do samples originating at the surface of a terrain sustaining a lower cumulative flux. In addition, the tail of the distribution is extended to greater numbers of impacts experienced for the shallowly buried tracers (Figures 2c) than for the surface tracers under lower flux (Figure 2a). With even greater initial burial (10 km) and the same 3x OLHD (Figure 2d), this tail of the distribution diminishes; most likely this occurs because the mean time a tracer must wait to be excavated is greater and, therefore, it spends less time exposed near the surface.

Ignoring those tracers that are never excavated, surprisingly small differences occur in the average number of impacts experienced by tracers originating from 0, 2, and 10 km depth, namely averages of

3.1, 2.6, and 2.3 impacts per tracer (Figures 2b,c,d). Therefore, samples from a wide range of depths may have quite similar impact-metamorphism histories.

Conclusions: 1) Lateral transport of samples found at the surface is not highly correlated with the impact flux, but is dominated by the rare, large impact events. 2) Although specimens collected from higher-flux terrains will have been impacted more frequently (even if they came from depths of 2 km) than would specimens collected from lower-flux terrains, specimens originating at 10 km depth have an impact history more closely corresponding to that of the lower-flux terrain specimens. 3) For a single terrain, samples originating from greater depths will have suffered only a slightly lesser average number of impacts than those originating closer to the surface; therefore, the degree of impact metamorphism is not strongly correlated with the depth of origin of the specimens.

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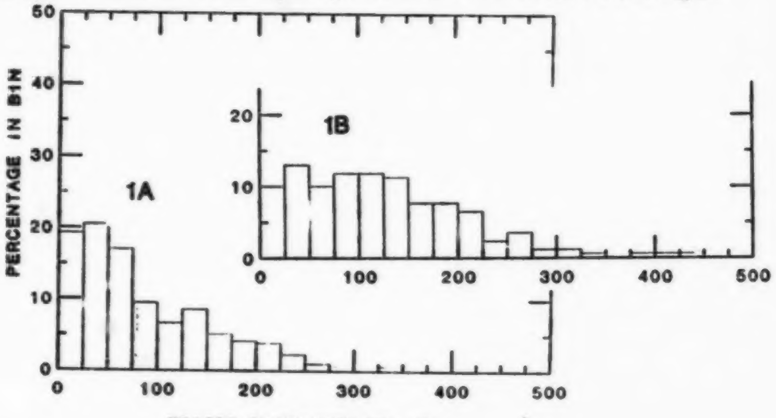
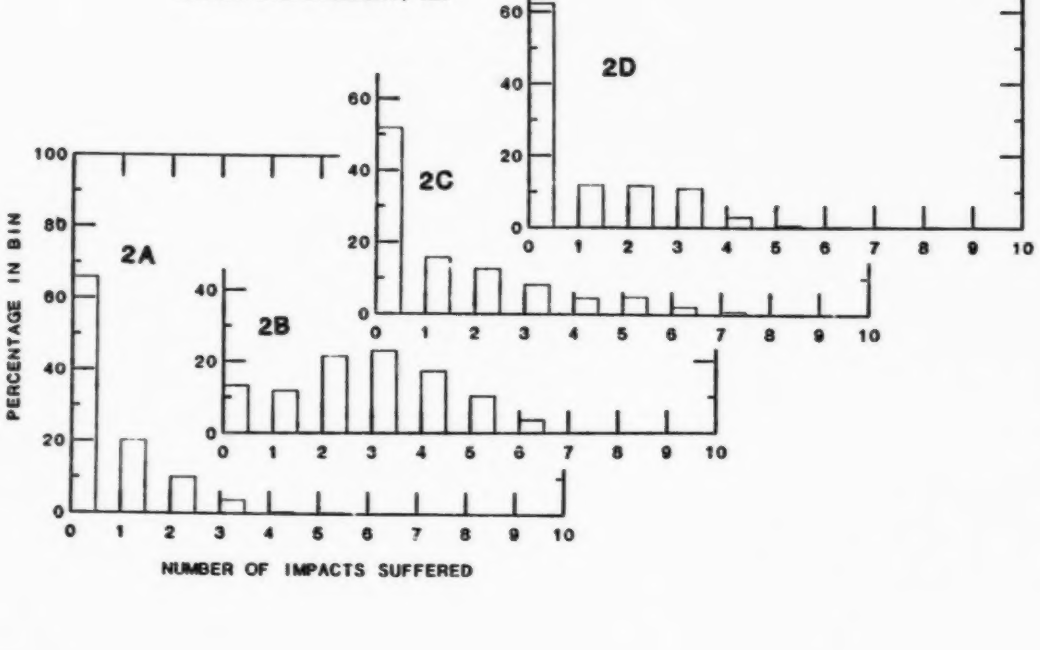
Figure 1: Displacement of tracers that have been excavated at least once. a) 1x OLHD. b) 3x OLHD.

Figure 2: 10 trials each of a) 1x OLHD, tracers at surface; b) 3x OLHD tracers at surface; c) 3x OLHD tracers at 2 km depth d) 3x OLHD tracers at 10 km depth.





STABLE ISOTOPIC STUDIES OF H,C,N,O AND S IN SAMPLES OF MARTIAN ORIGIN;

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The present day geochemical cycles of volatile elements through the various reservoirs on Earth are largely understood within the context of the planet's standing as a geologically and biologically evolved body. Furthermore, the nature of the primitive starting materials which coalesced to form the terrestrial planets has been to some extent established from studies of meteorites; the most volatile components will eventually be investigated from cometary samples. However, the evolutionary pathways which have led from conditions in the primitive solar nebula to the current geochemical balance on Earth are obscure, due to the lack of a geological record beyond 3.8×10^9 years. Thus, there is a need to observe directly the extent to which all planets have evolved, as these bodies may preserve evidence of the sorts of processes which were in operation on the early Earth (including those reactions which led to the formation of life).

In terrestrial studies stable isotope measurements of light elements (H,C,N,O and S) can be utilized to obtain insight into the conditions prevailing during formation of rocks of various types (i.e. igneous, metamorphic and sedimentary). In addition, isotopic measurements of the atmosphere, hydrosphere etc. have contributed to the understanding of the interaction of volatile reservoirs. A few examples illustrate the uses of stable isotope measurements; (i) the partitioning of oxygen isotopes between co-existing minerals at equilibrium allows calculation of the temperature of formation or metamorphism (e.g. 1); (ii) isotopic measurements of minerals such as carbonates can be used to infer the environmental conditions during precipitation and deposition (e.g. 2); (iii) for minerals which have undergone subsolidus reaction with aqueous fluids the imprinted isotopic signatures can be used to determine the extent and nature of alteration (e.g. 3); (iv) isotopic measurements of trace constituents (e.g. carbon and nitrogen in igneous rocks) help discern the involvement of different volatile reservoirs (e.g. 4,5). As Mars has been geologically active up until recent times, and shows clear evidence for the presence of fluid processes, it is envisaged that many applications of stable isotope studies will be appropriate to materials of martain origin (rocks, fines, gases, fluids,ices) provided samples are forthcoming.

It is probable that, in the first instance, samples returned from Mars will be surface or near-surface materials rather than fresh specimens of deep-seated origin. However, if it is accepted that SNC meteorites originate on Mars (see 6 for a review of the properties and the arguments which favour a martian origin) then such samples are already available in the laboratory for study (and indeed have been studied extensively). Notwithstanding the caveats regarding the origin of SNC meteorites, it is noteworthy that light element abundance and stable isotopic studies have been used to establish (i) their uniqueness amongst meteorites, their parent body sampling a reservoir which was slightly different from that of the Earth (7); (ii) the presence of shock-implanted atmospheric gases (8) and (iii) the existence of pre-terrestrial weathering products (9,10).

Perhaps the most important problem which could be addressed by light element studies of the sorts of specimen likely to be available from remote automatic sampling, would be the rôle of volatiles during evolution. Of fundamental importance here is the question of whether Mars was volatile-rich (11) or volatile-poor (12). An example of a specfic investigation concerns the interaction of CO_2 and H_2O within the regolith and at the surface. Over the lifetime of Mars, outgassing processes are thought to have placed between 140 and 3000 mbar of CO_2 into the atmosphere (13). This is postulated to be removed largely by carbonate formation implying the presence at some point of liquid water (13). The operation of processes which involve water (a prerequisite for life) is an extremely important issue and one which demands the application of all pertinent analytical techniques. Similarly, the martian regolith is known, from Viking measurements, to be sulphur-rich (14); interestingly, laboratory studies of SNC meteorites have demonstrated a surprisingly complex sulphur chemistry, which is probably unique amongst achondrites (15,16). The isotopic fractionation displayed by sulphur in different oxidation states may well be able to constrain formation conditions.

The only reliable way to fully comprehend the effects of volatile cycling through the mantle-crust and regolith-atmosphere-polar cap systems of Mars, is by analvses of appropriate returned samples. In order to interpret the record of geological activity in martian samples it will be necessary to understand how the past, or present, surface environment may have acted to disturb the primary characteristics of the rocks. The secondary processes, implied by SNC meteorite analyses, could be assessed by material not only from diverse locations, but also from different depths within the regolith to compare with samples from outcrops and the ambient atmosphere. It should be stressed that in order to achieve successful interpretation of the data, all materials needs to be contamination-free and, as such, the experience gained from acquisition and handling of lunar samples needs to be fully assimilated into the Mars sample return program.

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A REASON FOR SAMPLING MARTIAN ICE; J. Yatteau, Harvard U.

Reservoirs of H_2O and CO_2 that can exchange with the Martian atmosphere are currently changing in isotopic composition due to differential escape of light isotopes of hydrogen, oxygen and carbon from the atmosphere. Precise knowledge of the present isotopic compositions of H, O, and C can be used to infer the masses of exchangeable reservoirs of H_2O and CO_2, given knowledge of the escape fluxes. Escape fluxes can be predicted for hydrogen and oxygen with considerable confidence. The escape flux of carbon is more difficult to calculate. However, current escape fluxes are all susceptible to direct measurement from Mars orbit. Measurement of the isotopic compositions of H, O, and C in Martian ice samples with the precision of a terrestrial isotope laboratory would provide more useful information concerning the reservoir masses and evolution of H_2O and CO_2 on Mars than any other comparable set of measurements.

N89-18369

IN-SITU XRF AND GAMMA RAY SPECTROMETER FOR MARS SAMPLE RETURN MISSION;

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We propose a combined in-situ x-ray fluorescence (XRF) and passive gamma-ray spectrometer instrument for the chemical elemental analysis of various Martian surfaces and samples. The combined instrument can be carried on board a rover. The passive τ-ray or the neutron-excited τ-ray system would be used to determine the elemental composition of the Martian surface while the rover is in motion. The XRF system would be used to perform analysis either on the Martian surface or on collected samples when the rover is stationary. This latter function is important both in cataloguing the collected samples and in the selection of samples to be returned to earth. For both systems, data accumulation time would be on the order of 30 minutes. No sample preparation would be necessary.

XRF is a well-established and successful technique in performing in-situ chemical analysis of planetary surface samples. In previous planetary missions such as Viking and Venera, XRF measurements were made using radioisotopes as excitation sources and proportional counters as energy-dispersive detectors. Although our instrument does not preclude the use of radioisotopes we emphasize here the use of a miniature x-ray generator as the excitation source and mercuric iodide as the energy-dispersive detector.

A low-power (10 W) battery-operated x-ray generator was developed at Goddard Space Flight Center several years ago. The x-ray generator weighs 6 kg, is capable of supplying 68 kV and 100 microamps of anode current, and is powered by a 18-V battery. It has a grounded anode with no high-voltage cables. Such an x-ray generator with variable spectral distribution can provide far higher x-ray fluxes than radioactive sources. Recently, similar battery-operated x-ray generators have also become commercially available.

The energy resolution of room-temperature mercuric iodide detectors has been improving steadily in recent years. Under laboratory conditions it is now gradually approaching the resolution of cooled Si(Li) detectors. However, presently available mercuric iodide detectors with good stability and acceptable energy resolution for the Mars sample return mission have sensitive areas of only a few mm^2. Such small detection areas need not be a problem with the proposed XRF instrument because of the high x-ray flux available from the x-ray generator. Therefore the combination of a miniature x-ray generator with a mercuric iodide detector should provide an in-situ XRF instrument with energy resolution and detection efficiency not achievable by previous planetary instruments.

Table I lists some of the elements which can be detected by a passive τ-ray spectrometer using a 7.5x7.5 cm NaI(Tl) crystal. The expected integration time for each element to reach 10% uncertainty is calculated using methods similar to those in Evans and Squyres[1]. The neutron spatial and energy distribution, and consequently the τ-ray flux, is highly sensitive to the H content. Therefore calculations were carried out for different cases of soil and H_2O: with 1% H_2O, with 25% H_2O, and with a "dry" layer of soil with 1% H_2O covering soil with 25% H_2O for three different thicknesses of the top layer. Table I shows that while the rover is in motion integration time on the order of 30 minutes could provide sufficient information concerning H, K, and Fe. When the rover is stationary, most of the elements in Table I could be analyzed in a few hours. Of course, if weight and power constraints permit the use of a neutron generator, the integration times in Table I could be reduced substantially, and additional elements could be detected.

Table I. Integration time (hours) to measure an element to 10% uncertainty by the passive τ-ray spectrometer

		Homogeneous soil + H_2O		Layer soil with 1%H_2O over soil+25%H_2O		
				Thickness of upper layer		
Element	Mode*	soil+ 1%H_2O	soil+ 25%H_2O	20g/cm^2	50g/cm^2	100g/cm^2
Fe	C	0.7	0.3	0.5	1.1	1.1
Si	C	4.0	1.6	2.8	7.6	7.8
Cl	C	3.5	1.4	2.3	5.8	5.9
H	C	68.0	0.03	0.3	5.7	74.0
Si	I	0.1	0.5	0.2	0.1	0.1
Mg	I	2.1	11.0	3.7	2.5	2.1
Fe	I	0.2	1.0	0.3	0.2	0.2
K	R	0.3	0.5	0.4	0.3	0.3
Th	R	6.0	9.4	7.0	6.0	6.0

*Mode: C – τ rays produced by neutron capture
I – τ rays produced by neutron inelastic scattering
R – τ rays produced by natural radioactivity

It should be noted that both the XRF and the τ-ray spectrometer will share much of the analyzing electronics beyond their respective amplifier stage. Because of the relatively coarse resolution of the NaI(Tl) spectrometer, a single analog-to-digital converter will be sufficient to accommodate both XRF and τ-ray spectra. Thus economy in both weight and cost can be realized in such a combined XRF and τ-ray instrument.

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N89-18370

THE RECORD OF MARTIAN CLIMATIC HISTORY IN CORES AND ITS PRESERVATION

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Among the questions to be addressed by a Mars Sample Return Mission are the history of the martian climate and the mechanisms that control the volatile cycles. Unfortunately, the evidence that bears most strongly on those issues lies in the volatile distribution in, and physical configuration of, a very delicate and volatile system: the uppermost martian regolith. This study identifies some useful measurements to be made on returned samples of the regolith, and a few of the many critical considerations in ensuring the usefulness of returned samples.

Among the most difficult properties of the regolith to examine via returned sample are: the vertical distribution of ground ice, the vertical distribution of adsorbed H_2O, and the amount of adsorbed CO_2.

The ability of the martian regolith to transport H_2O is very limited; only ~ 1 - 10 g H_2O cm^{-2} can exchange with the regolith per obliquity cycle. Therefore the abundance and distribution of H_2O through the uppermost regolith is the product of an extensive history of H_2O migration. testing for the presence or absence of ground ice in the shallow, high-latitude regolith would provide a measure of our fundamental understanding of the martian H_2O cycle. If present, it would confirm our model of the high-latitude regolith as a sink for H_2O. The depth at which ground ice is found could be related to the thermal properties of the regolith, which control propagation of heat to the ice, and to the long-term average atmospheric partial pressure of H_2O. If absent, it would cause a re-examination of our models, and could lead to constraints on the erosion/deposition rates of the regolith.

Whether there is ground ice present or not, there is certain to be a finite amount of adsorbed H_2O. Diurnal, seasonal and long-term cycles of temperature and P_{H_2O} act to modify the abundance and distribution of the adsorbate. Because the depth to which each cycle acts is proportional to the square root of the cycle's period, the depth profile of H_2O adsorbate may be invertible to yield information on the history of the H_2O cycle. Further laboratory and numerical work is necessary to develop the possibility.

The largest portion of exchangeable CO_2 in the martian environment is physically adsorbed onto the regolith. Models suggest that at high obliquity, the regolith desorbs enough CO_2 to raise the atmospheric pressure by several millibars. We would like to measure the amount of CO_2 available for exchange with the atmosphere. One concern is the competition for adsorption sites by H_2O vapor. Another is the degree to which CO_2 is chemisorbed onto the particulate material, and how that might alter the soil's surface functional groups. For example, the difference between chemisorption onto inorganic hydroxyl groups and simple outer-sphere complexation on siloxane ditrigonal cavities would be substantial in terms of adsorptive exchange.

The interaction of the regolith and atmosphere is also controlled by the small-scale structure of the regolith. For example, the thermal conductivity of the regolith can depend upon the geometry of packing, the nature of grain boundaries, and the presence of intragrain bonding, which might allow conduction between grains to compete with gaseous conductivity. The pore size, in relation to the mean free path of a gas molecule determines the gas-phase conductivity, especially important in loose, unbonded material.

The pore size distribution determines the efficacy of volatile transport through the regolith, and the capacity of the regolith to buffer climate changes. If possible, we would like to measure the pore size distribution in a number of relatively undisturbed samples.

We conclude that there is a great deal to be learned from examination of the uppermost martian regolith if the chemical state and structure could be preserved.

Cores are the optimal method for retrieving and examining the material in the shallow martian regolith. A great deal of work has been done on core acquisition, although several aspects bear additional emphasis. One of the first is the extreme importance of using a minimum penetration rate, which is proportional to the temperature of the core at the bit during drilling. Because of the extreme volatility of physically adsorbed CO_2, the core must be kept at the minimum ambient temperature. The drill stem should be constructed of low thermal conductivity material to avoid transporting heat along the stem during drilling operations.

Climate and Cores

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Preservation of the cores after drilling is must also be addressed. There should be rapid transfer from the drill stem to the storage container. The seasonal thermal profile is such that the temperature at the surface is different from the temperature at depth. Since the cores are to be no more than 1 - 2 cm in diameter, they will approach the surface temperature, which may differ from their original temperature by > 40 K, in a matter of minutes. There is the possibility of escape of gas at the margins of the core, and for migration of gas in response to the changing temperature profile. If possible, the transfer from core stem to storage should take place at night, although this will place constraints on our ability to inspect the core and to make go-nogo decisions on storage. In any event, the leisurely examination of the core in the full sunlight will cause an unacceptable loss of information, and should be absolutely disallowed.

The typical lifetime of the cores after extraction, and before examination, will be several hundred days, during which time significant alteration is possible. The optimal solution to this problem is to return subsamples of taken at pre-determined intervals along core. The subsamples should be stored and transported separately. In addition to preserving the gradients, albeit at degraded resolution, the subsampling technique would allow more sample to be returned, since returning the entire core is probably wasteful of mass. Our calculations suggest that the uncertainty in average P_{H_2O} associated with a 5 cm uncertainty in the position of the interface is only ~10%. A third reason for the return of small subsamples of the cores is the importance of preserving the pore sise distribution of the regolith. Smaller samples place less load on contact points during acceleration, and are less likely to result in result in compaction.

If it proves prohibitively expensive or complex to implement adequate techniques for the acquisition and subsectioning of contiguous cores, then thought should be given to abandoning the coring tool altogether, and simply returning samples dredged from a variety of depths in adjacent excavations. In the absence of local variations in surface units, the volatile distribution in the subsurface should be sufficiently homogeneous to make all locations equally representative.

The samples should be continuously monitored after excavation, and provision should be made for cooling of the sample container should the temperature rise substantially above the temperature at the time of collection.

Finally, there should be no sterilisation whatsoever on the core samples to be analysed for the state and distribution of major volatiles. Even heating samples to room temperature is likely to result in wholesale chemical and physical redistribution of volatile species.

Cores should be collected from two well separated latitudes on the surface of the planet. The goal in so doing would be to establish a the latitudinal distribution in the volatile abundances of the regolith, both as an historical indicator of the past climate, and as an aid in understanding how the martian climate will respond to future insolation variations. The cores should be at least 1 m in depth, in order to sample volatile distributions that are indicative of both annual and longer term averages. Since only subsamples of the cores are logical for return, the option of drilling to 2 m might be explored, depending on the latitude at which drilling is to take place. One core should be from latitudes poleward of 40°, in order to sample the hard-frozen permafrost. A second lander/rover should be included in the mission for redundancy and targeted for the low-latitude regolith.

With these criteria and others, we have selected two options for landing sites for a lander-rover tandem. The additional criteria we have considered are as follows: Both landing sites should be in geologically complex areas, with the opportunity to visit a maximum number of terrains with total traverses of no more than 100 km; at least one of the rovers should be able to sample volcanic terrains. Our high-latitude site is at 316°W - 50°30' N. It is very near the boundary of the northern plains and cratered highlands. The rover should be able to example the stratigraphy of the boundary. The second site is at 61°30'N - 0°30'N. This site is in the ridged plains material, and very near the channel system that runs north from Juventae Chasma. The channel system forms a geologic boundary between the volcanic terrains on the west, and the heavily cratered terrain on the east.

N89-18371

PRESENT IMAGING LIMITATIONS TO PROVIDING A GEOLOGICAL ASSESSMENT OF POTENTIAL SAMPLE RETURN SITES ON MARS.

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A Mars sample return mission will provide a tremendous increase in knowledge about the region explored by the roving vehicle. However, presently there are some important limitations on the extent to which the geology of a potential site can be understood PRIOR to landing the sample return vehicle on Mars. These limitations could affect not only the potential science return of the mission but also the safety of the vehicle.

Orbital imaging is the single most important data source required in the selection of potential landing sites for the sample return mission. During the Viking mission images with 80 m/pixel resolution formed the primary data set used in selecting the landing sites and at the Lander 2 location this resolution was insufficient to reveal the full extent of potentially hazardous blocks at the landing site. What spatial resolution is necessary to adequately assess the relative roles of the geologic processes that have been active at a potential landing site? The Viking Orbiter images provide some useful clues to this important question.

The Viking Orbiters returned over 51,000 images of the martian surface (1) but only a small fraction of these images will be useful in assessing the details of the surface geologic history. It has been shown that aeolian features evident at 9 m/pixel resolution are not visible in images with >50 m/pixel resolution (2,3). Only about 1% of the Viking images have a spatial resolution of <10 m/pixel and are relatively free of obscuring dust or haze (3). Even increasing the resolution limit to <20 m/pixel only results in about 2700 useable images (data from 4; Fig. 1). Figs. 2 to 4 illustrate that 16 m/pixel resolution is sufficient to distinguish stratigraphic relationships, important to a proper evaluation of the geologic history, that are not evident at 100 m/pixel resolution. It is quite unlikely that all (or even most) of the proposed landing areas will be included in images with sufficient resolution to determine the history of the surface (particularly the extent of aeolian modification). The high resolution images from Mars Observer Camera will be essential to the site selection process.

Non-imaging remote sensing can provide information complimentary to the high resolution images. However, non-imaging data cannot take the place of missing high resolution images. Reflected and emitted radiation provide valuable constraints on the chemical and physical makeup of the surface but this information is relevant to only the uppermost materials, at best the top several centimeters of the surface. Since the surface materials are greatly affected by aeolian processes (5,6,7), the remote sensing results may not be well correlated with the geologic history of the surface (7).

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Figure 1 (next page). Cumulative number of Viking Orbiter images as a function of slant range and spatial resolution. Note that almost one half of the images with spatial resolution <20 m/pixel are not useable due to obscuring atmospheric dust or haze. Data are from (4).

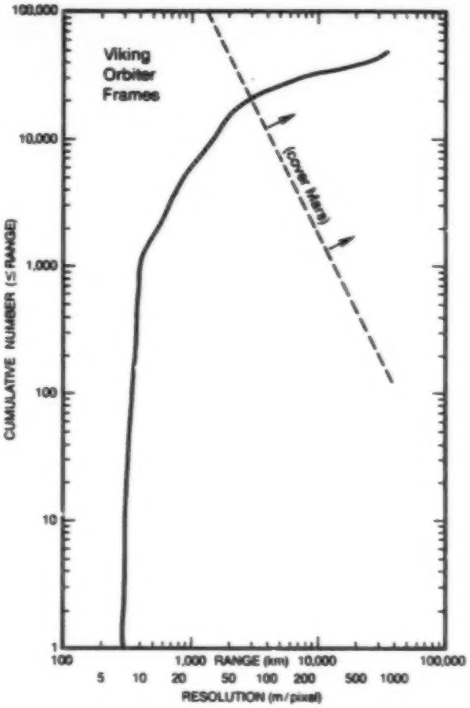

Figure 1.

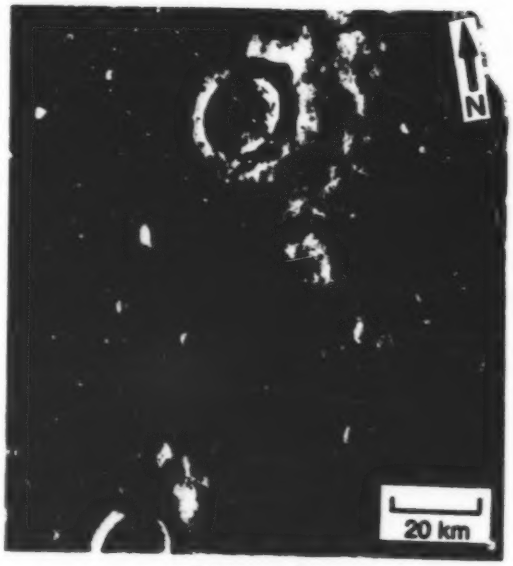

Figure 2.

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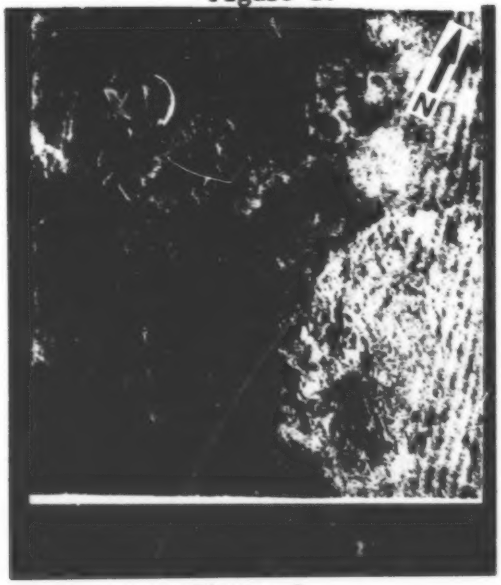

Figure 3.

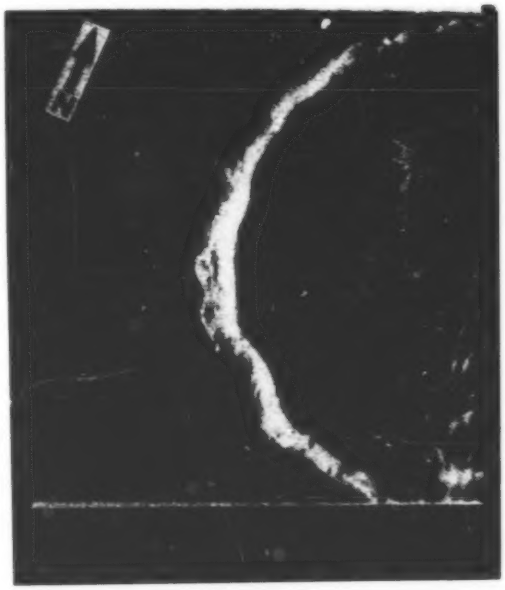

Figure 4.

Figure 2. 100 m/pixel image of the northern Utopia plains. Dashed lines indicate area shown in Figures 3 and 4. Frame 10B70, 42°N, 272°W.

Figures 3 and 4. 16 m/pixel images. Note that the ejecta is covered by the smooth plains material. Similarly, the crater interior deposits may be related to material that was draped over the surface. The crater interior morphology could result from erosion of this material. Frames 425B11 and 7.

N89-18372

COMPUTER MODELING OF THE MINERALOGY OF THE MARTIAN SURFACE, AS MODIFIED BY AQUEOUS ALTERATION;

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INTRODUCTION: Mineralogical constraints can be placed on the martian surface by assuming chemical equilibria among the surface rocks, atmosphere and hypothesized percolating groundwater. We have initiated a study of possible martian surface mineralogy, as modified by the action of aqueous alteration, using the EQ3/6 computer codes [1]. These codes calculate gas fugacities, aqueous speciation, ionic strength, pH, Eh and concentration and degree of mineral saturation for complex aqueous systems. Thus, these codes are also able to consider mineralogical solid solutions. These codes are able to predict the likely alteration phases which will occur as the result of weathering on the martian surface. Knowledge of the stability conditions of these phases will then assist in the definition of the specifications for the sample canister of the proposed martian sample return mission.

MODELING: In our modeling we assumed that 1) all chemical reservoirs were in equilibrium, 2) the initial composition of the martian surface is adequately modeled by the mineralogy of the Shergotty meteorite [2-3] and 3) water was available to react with the rocks. The initial conditions are given below.

ATMOSPHERE: $pO_2=10^{-5}$, $pCO_2=10^{-2.2}$, $pH_2O=10^{-5}$, $pN_2=10^{-4}$, $P_{total}=0.01$ atm

WATER: 2°C, dissolved $CO_2=10^{-3.3}$m, dissolved $O_2=10^{-7.7}$m [4]

ROCKS: The modal mineralogy of the Shergotty meteorite [2-3]

These computer codes model a process of reacting solid mineral phases with a constant volume of solution. Thus, the "titrated" rocks will initially dissolve and then, as saturation of various components is reached, new phases precipitate. The codes have been operated in two modes; in the "closed" mode early-precipitated phases are free to re-equilibrate with later phases and solutions as the reaction proceeds, whereas in the "open" mode precipitating phases are removed from further reaction with the system. Thus, the latter operational mode more nearly resembles the action of a transient aqueous fluid while the former mode resembles a stagnant system.

Because of the lack of the requisite thermochemical data for minerals at temperatures below 0°C, these models were run for a temperature of 2°C. This figure is above the average martian surface temperature (~-23°C), but within the range of values modeled by Viking IRTM data (-143 to 7°C) [5]. The results presented here will be applicable to materials at lower temperatures, however, since aqueous alteration due to the action of "unfrozen water" has been documented well below 0°C [6]. Obviously the rate of aqueous alteration would be the greatest at the highest temperatures, where liquid water would be more available and reaction rates faster. On Mars this would be in the mid to low latitudes in the spring and summer [5].

RESULTS: The results of the "closed" and "open" modeling modes were essentially identical, and are summarized in Figure 1. The alteration phases which form are shown along the vertical axis. The horizontal axis indicates (in a logarithmic scale) the percent of rock which has reacted at the point at which each alteration phase precipitates and, for some phases, redissolves. Narrow lines indicate where a mineral precipitates, and a wide line indicates where a mineral predominates among the precipitating phases.

Lines pinch out where a mineral re-dissolves. The nontronite is more accurately a mix of ~88% Ca-Mg nontronite and ~12% beidellite. The calcite actually contains ~7% magnesite and <1% siderite.

DISCUSSION: Hematite and gibbsite are calculated to precipitate only during the earliest stages of aqueous alteration, re-dissolving as alteration proceeds. The obvious red coloration of martian fines, however, implies Fe^{3+} oxide pigmentation and indicates that compositional evolution was more complex than allowed by this single-stage model. No sulfates or chlorides are predicted to precipitate because the starting rock composition did not provide sufficient concentrations of these species. Nontronite is a dominant weathering phase in this model, which is consistent with some interpretations of the Viking XRF results [7]. Alteration to this smectite-dominated assemblage requires at least 0.1% reaction. However, unless degrees of alteration exceed approximately 0.01%, clay products should be dominated by nontronite and kaolinite, in contrast with the smectite-like composition inferred from Viking results. It is also interesting to note that if no more than approximately 0.5% of available rock is subjected to aqueous alteration carbonates should not form. Alteration to approximately 0.1-0.5% completion can apparently yield nontronite without carbonates. The subsequent behavior of the predicted alteration phases upon drying is beyond the scope of this simple model. Nevertheless, this model indicates that nontronite can form in cold non-saline environments, quite unlike the hot, saline environments which are characteristic of its most well-known terrestrial environments [8].

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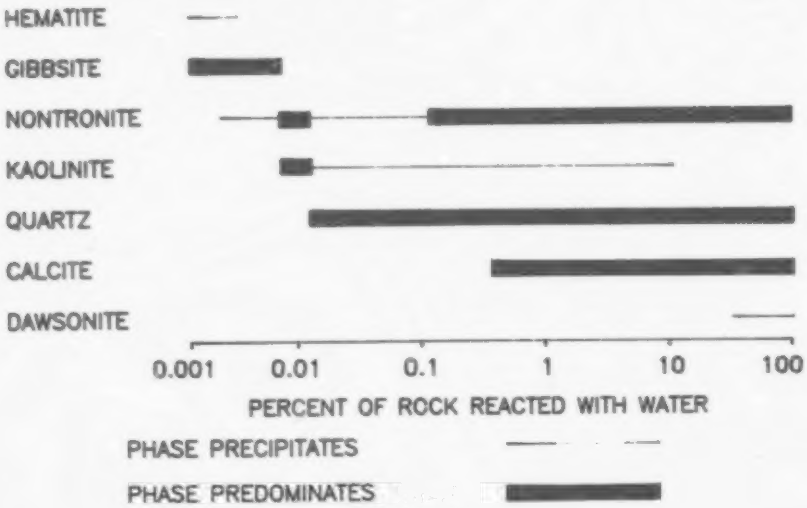

FIGURE 1

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